May 20, 2016

VIA FAX and Federal Express

Amy Lueders, State Director
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Dear Ms. Lueders:

The Center for Biological Diversity, Friends of the Earth, Food and Water Watch, Great Old Broads for Wilderness, and Sierra Club hereby file this Protest of the Bureau of Land Management ("BLM")'s planned July 20, 2016 oil and gas lease sale, and Environmental Assessment DOI-BLM-NM-P020-2016-0588-EA, pursuant to 43 C.F.R. § 3120.1-3. We formally protest the inclusion of each of the following 36 parcels, covering 13,876.08 acres in the Carlsbad Field Office in New Mexico:

NM-201607-001	NM-201607-013	NM-201607-026
NM-201607-002	NM-201607-014	NM-201607-027
NM-201607-003	NM-201607-015	NM-201607-028
NM-201607-004	NM-201607-016	NM-201607-029
NM-201607-005	NM-201607-017	NM-201607-030
NM-201607-006	NM-201607-018	NM-201607-031
NM-201607-007	NM-201607-019	NM-201607-032
NM-201607-008	NM-201607-021	NM-201607-033
NM-201607-009	NM-201607-022	NM-201607-034
NM-201607-010	NM-201607-023	NM-201607-035
NM-201607-011	NM-201607-024	NM-201607-036
NM-201607-012	NM-201607-025	

PROTEST

I. Protesting Party: Contact Information and Interests:

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This Protest is filed on behalf of the Center for Biological Diversity, Friends of the Earth, Food and Water Watch, Great Old Broads for Wilderness, and Sierra Club, and their boards and members by:

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The Center for Biological Diversity ("the Center") is a non-profit environmental organization dedicated to the protection of native species and their habitats through science, policy, and environmental law. The Center also works to reduce greenhouse gas emissions to protect biological diversity, our environment, and public health. The Center has over 1 million members and online activists, including those living in New Mexico who have visited these public lands in the Pecos District for recreational, scientific, educational, and other pursuits and intend to continue to do so in the future, and are particularly interested in protecting the many native, imperiled, and sensitive species and their habitats that may be affected by the proposed oil and gas leasing.

Friends of the Earth is a 501(c)(3) organization with over 33,000 members and 496,000 activists nationwide. Friends of the Earth fights to create a more healthy and just world. Our current campaigns focus on promoting clean energy and solutions to climate change, ensuring the food we eat and products we use are safe and sustainable, and protecting marine ecosystems and the people who live and work near them.

Food and Water Watch champions healthy food and clean water for all. We stand up to corporations that put profits before people, and advocate for a democracy that improves people's lives and protects our environment.

Great Old Broads for Wilderness ("Broads") is a national non-profit organization that engages and ignites the activism of elders to preserve and protect wilderness and wild lands. With more than 5,500 members and friends, Broads gives voice to the millions of older Americans who want to protect their public lands as Wilderness for this and future generations. Broads has three chapters, called "Broadbands" in New Mexico: in Albuquerque, Santa Fe and Silver City.

The Sierra Club is a national nonprofit organization of approximately 625,000 members dedicated to exploring, enjoying, and protecting the wild places of the earth; to practicing and promoting the responsible use of the earth's ecosystems and resources; to educating and enlisting humanity to protect and restore the quality of the natural and human environment; and to using all lawful means to carry out these objectives. The Rio Grande Chapter of the Sierra Club has approximately 7,300 members in the state of New Mexico. The Sierra Club has members who live and recreate in the Pecos District. Sierra Club members use the public lands in New Mexico, including the lands and waters that would be affected by actions under the lease sale, for quiet recreation, scientific research, aesthetic pursuits, and spiritual renewal. These areas would be threatened by increased oil and gas development that could result from the proposed lease sale.

II. Statement of Reasons as to Why the Proposed Lease Sale Is Unlawful:

BLM's proposed decision to lease the parcels listed above is substantively and procedurally flawed for the reasons discussed below, as well as those discussed in our comments on the Preliminary Environmental Assessment (PEA) on March 8, 2016 and in our scoping

comments on December 30, 2015. This protest incorporates both of our previous letters by reference herein. The proposed lease sale is unlawful for the following additional reasons:

A. BLM Violates the National Environmental Policy Act ("NEPA")

For proposed "major Federal actions significantly affecting the quality of the human environment," agencies must prepare an EIS in which they consider the environmental impact of the proposed action and compare this impact with that of "alternatives to the proposed action." See 42 U.S.C. § 4332(2)(C); Pennaco Energy, Inc. v. United States DOI, 377 F.3d 1147, 1150 (10th Cir. 2004). To determine whether an action will have a significant environmental impact, BLM can first prepare an environmental assessment ("EA"). 40 C.F.R. §§ 1501.4, 1508.9; Ohio Valley Envtl. Coal. v. Hurst, 604 F. Supp. 2d 860, 870 (S.D. W. Va. 2009) ("If the agency cannot readily determine whether an action will significantly affect the environment, then it must prepare an environmental assessment [] that discusses the proposed action, alternatives, and the environmental impacts of the proposed action and its alternatives."). If the EA reveals that the project will have a significant effect on the quality of the human environment, then BLM must prepare a detailed, written EIS. 42 U.S.C § 4332(2)(C).

BLM's "Finding of No Significant Impact" ("FONSI") and consequent decision not to prepare an EIS ignore both the high degree of uncertainty and the substantial controversy regarding the effects that the proposed action will have on the quality of the environment. Furthermore, BLM's erroneous finding is owing to BLM's failure to take a hard look at the environmental, public health, and safety concerns that were raised in scoping.

Despite NEPA's requirement that agencies undertake environmental analysis at the earliest possible time and prior to irretrievable commitment of resources, as well as our requests for an adequate environmental analysis, BLM has chosen to move forward with the lease sale without thoroughly analyzing the environmental impacts in an EIS, because BLM believes "the impacts of leasing the fluid minerals estate in the areas described with this EA have been previously analyzed in the Carlsbad Resource Management Plan and Final Environmental Impact Statement (BLM 1988); the Carlsbad Resource Management Plan Amendment and Final Environmental Impact Statement for Oil and Gas Resources (BLM 1997); and the Roswell Resource Area Resource Management Plan and Final Environmental Impact Statement (BLM 1997)" and because "[t]he lease stipulations that accompany the tracts proposed for leasing would mitigate the impacts of future development on these tracts." [1]

We first disagree that the presently foreseeable impacts of leasing could have been sufficiently analyzed in plans that were signed in 1988 and 1997. With the exception of the 2008 Special Status Species Resource Management Plan Amendment ("2008 RMPA"), which covers only issues relating to the lesser prairie-chicken and the sand dune lizard, these RMPs have not been revised in decades and therefore do not address the emergence of new and significant information, including but not limited to that relating to the new and dangerous extraction methods of hydraulic fracturing (or "fracking") and horizontal drilling, or the increased seismic risks that stem from such extraction methods. Nor do these RMPs include *any* analysis of the

[1] U.S. Bureau of Land Management, Finding of No Significant Impact, Project: July 2016 Competitive Oil and Gas Lease Sale, EZ Log Number: DOI-BLM-NM-P020-2016-0588-EA (2016) ("FONSI").

foreseeable indirect impacts of greenhouse gas ("GHG") emissions from extraction, transport, and combustion of leasing federal fossil fuels on climate, public health, and wildlife resources.

We also disagree that BLM's vague and speculative lease stipulations sufficiently reduce the identified impacts to a minimum. The stipulations are severely lacking in detail or scientific support of any kind. The EA does not cite to any data or studies that would show any efficacy of the allegedly protective measures. In fact, the only assurance BLM can give the public that the mitigation measures will be successful is the conclusory nature of the mitigation measures themselves. One example is BLM's analysis of the impacts pertaining to "cave and karst features" which provide direct conduits leading to groundwater. BLM's description of potential impacts includes the fact that "these conduits can quickly transport surface and subsurface contaminants directly into underground water systems and freshwater aquifers without filtration or biodegradation as a result of the development of oil and gas leases."[2] Furthermore, contaminates spilled or leaked into or onto cave and karst zone surfaces and subsurfaces could lead "directly" to the "disruption, displacement, or extermination of cave species and critical biological processes."[3] In extreme cases, a buildup of hydrocarbons in cave systems due to surface leaks or spills could cause underground ignitions or asphyxiation of wildlife or humans within the cave. BLM's list of severe threats from oil and gas production near these features goes on. However, the only protective measure mentioned in the EA is a stipulation which prohibits surface occupancy within 200 meters of any known cave or karst feature or system. BLM does not cite to or perform any analysis of research, studies or data to show the efficacy of the 200 meter buffer. Instead, BLM only concludes that "[a]ttaching this stipulation would minimize any potential impacts to the resource." This is not sufficient to meet the requirements of NEPA or to support a FONSI. See Wyo. Outdoor Council v. United States Army Corps of Eng'rs, 351 F. Supp. 2d 1232, 1251 (D. Wyo. 2005) ("A 'perfunctory description' or a 'mere listing' of mitigation measures, without supporting analytical data, is insufficient to support a finding of no significant impact.") (citing Nat'l Parks & Conservation Ass'n v. Babbitt, 241 F.3d 722, 734 (9th Cir. 2001)); and id., at 1249 ("…the mitigation measures must be more than a possibility. They must be imposed by statute or regulation or have been so integrated into the initial proposal that it is impossible to define the proposal without the mitigation."). BLM's conclusion of no significant impact is not supported by any reasoned explanations, and hence is arbitrary and capricious.

Finally, BLM's EA similarly fails to take a "hard look" at not only the issues that were completely omitted from the EA, but also issues that BLM mentioned in the EA but failed to adequately analyze. The EA does not, for example, take any look at the issue we raised in our comment on the PEA concerning the potential impacts of oil and gas exploration and development near a mixed nuclear-waste repository. New Mexico's Waste Isolation Pilot Plant (WIPP) is located just 25 miles east of Carlsbad.[4] The EA does not at all consider the implications of allowing oil and gas drilling operations, especially unconventional extraction methods such as hydraulic fracturing, so close to the waste storage. As discussed in our scoping

[2] U.S. Bureau of Land Management, Environmental Assessment for July 2016 Competitive Oil and Gas Lease Sale Carlsbad Field Office DOI-BLM-NM-P020-2016-0588-EA (2016) ("EA") at 53.
[3] *Id.*
[4] Tracy, Cameron L. et al., Policy: Reassess New Mexico's nuclear-waste repository, NatureNews (Jan 13, 2016) available at http://www.nature.com/news/policy-reassess-new-mexico-s-nuclear-waste-repository-1.19135

comments, hydraulic fracturing is known to cause earthquakes which is more cause for concern about using the technique where tons of radioactive material are being stored.[5] Although BLM acknowledges several other serious concerns that we raised in scoping and in our comments on the PEA, BLM does not provide any explanation for its conclusion that these foreseeable impacts are not significant. BLM failed to take a "hard look" at any of the issues we have raised in our letters.

i. It is Unlawful to Proceed with the Lease Sale without Undertaking a Site-Specific Environmental Assessment.

BLM's deferral of site-specific analysis until the APD stage is unlawful under NEPA, its implementing regulations, and legal precedents. Courts, including the Tenth Circuit, have repeatedly rejected BLM's claim that it does not have to address mitigation measures or perform site-specific NEPA analyses until an APD is received. As we have stated time and again, BLM is required to perform and disclose an analysis of environmental impacts *prior* to the irretrievable commitment of resources. N.M. ex rel. Richardson v. BLM, 565 F.3d 683, 716 (10th Cir. 2009) (NEPA and the CEQ regulations provide that assessment of a given environmental impact must occur as soon as that impact is "reasonably foreseeable," citing 40 C.F.R. § 1502.22, and must take place before an "irretrievable commitment of resources" occurs, citing 42 U.S.C. § 4332(2)(C)(v)); See also Pennaco Energy, Inc. v. United States DOI, 377 F.3d 1147, 1160 (10th Cir. 2004) (Agencies are required to satisfy NEPA before committing themselves irretrievably to a given course of action, so that the action can be shaped to account for environmental values.). Because a lessee has certain, defined surface use rights, see e.g. 43 C.F.R. § 3101.1-2 ("[a] lessee shall have the right to use so much of the leased lands as is necessary to explore for, drill for, mine, extract, remove, and dispose of all the leased resource in a leasehold . . ."), the point of irretrievable and irreversible commitment occurs at the point of lease issuance. S. Utah Wilderness All. v. Norton, 457 F. Supp. 2d 1253, 1256 (D. Utah 2006).

Although BLM attempts to characterize leasing as mere administrative paperwork that cannot result in any impacts to the environment,[6] NEPA and governing Tenth Circuit decisions have made clear that the test depends upon existing environmental circumstances, not upon "the formalities of agency procedures," and as such requires a "fact-specific inquiry." Richardson, 565 F.3d at 717. The "operative inquiry" is two-fold: First we must ask whether the lease constitutes an "irretrievable commitment of resources." The Tenth Circuit has concluded that issuing an oil and gas lease without an NSO stipulation constitutes such a commitment. Id. at 717 (citing to Pennaco Energy, 377 F.3d at 1160; and Sierra Club v. Peterson, 717 F.2d 1409, 1412-1414 (D.C. Cir. 1983)). Second, we must ask whether all "foreseeable impacts of leasing" have been taken into account before leasing can proceed. Id. Given BLM's failure to provide adequate site-specific review of the parcels, we assert that they have not been taken into account.

ii. BLM Failed to Take a Hard Look at any of the Potential Impacts of the Proposed Action Raised in our Previous Comment Letters on the Sale

[5] *Id.*
[6] EA at 33 ("The act of leasing parcels would, by itself, have no impact on any resources in the CFO.").

As BLM has not provided any environmental review of the parcels at issue or any site-specific analysis of the potential environmental impacts from the proposed action, we incorporate by reference herein our comments on the PEA, which discuss BLM's failure to take a hard look at the foreseeable impacts from the lease sale, oil and gas development, and the use of hydraulic fracking technologies. In particular, BLM failed to take a hard look at the potential impacts of the proposed action on water resources, air quality, climate change, human health and safety, seismicity, and sensitive species of plants and wildlife. We expand upon the following issues:

a. BLM does not Take a Hard Look at Impacts to Lesser Prairie-Chicken

The lesser prairie-chicken (or "LPC") is a special status species. Although the U.S. District Court for the Western District of Texas has vacated the Fish and Wildlife Service's ("FWS") earlier decision to list the species under the Endangered Species Act, the FWS has strongly indicated that threats to the species' continued existence, including oil and gas impacts on both occupied and suitable habitat, remain unabated:

> Even if members of the species are not currently found in certain areas, suitable habitat that lies in close proximity to focal and connectivity habitat is important to the species. The species' numbers are very low and its habitat is already highly fragmented. First Shaughnessy Declaration ¶ 4, 26. On these facts, the loss and fragmentation of even relatively small amounts of existing and suitable habitat can easily put the species on a path towards a "death spiral" from which it cannot recover, as the Service has seen for similar prairie grouse species such as the now-extinct heath hen and endangered Attwater's prairie-chicken. Norris Declaration ¶ 6, n.1. See also First Shaughnessy Declaration ¶ 4 (stating that the species is "exceptionally vulnerable to small changes on the landscape, especially at its currently reduced numbers").

Permian Basin Petroleum Ass'n v. U.S. Department of the Interior, No. 7:14-CV-0050-RAJ, Defendants' Additional Filing in Support of Their Opposed Motion to Amend the Judgment 7-8 (Jan. 27, 2016). Although the lesser prairie-chicken is not currently subject to Endangered Species Act protection given the vacatur of the listing decision, it remains a candidate species pending new action by the FWS, and therefore a special status species subject to the BLM's sensitive species policy. Given the FWS's acknowledgment that "the loss and fragmentation of even relatively small amounts of existing and suitable habitat can easily put the species on a path towards a "death spiral" from which it cannot recover," it is critical that BLM carefully assess the potential impacts of leasing on suitable lesser prairie-chicken habitat under NEPA, FLPMA, and its sensitive species policy.

BLM Manual 6840 provides that "[a]ll Federal candidate species, proposed species, and delisted species in the 5 years following delisting will be conserved as Bureau sensitive species."[7] The Objective of Manual 6840 is "[t]o initiate proactive conservation measures that

[7] U.S. Bureau of Land Management, Manual 6840 – Special Status Species Management (Dec 12, 2008) ("BLM Manual") at § .01.

reduce or eliminate threats to Bureau sensitive species to minimize the likelihood of and need for listing of these species under the ESA."[8] Manual 6840 further states that it is the BLM's Policy to promote "conservation and to minimize the likelihood and need for listing" Bureau sensitive species.[9]

Furthermore, pursuant to Manual 6840 it is the responsibility of State Directors to not only inventory BLM lands to determine the occurrence of BLM special status species, but also to determine "the condition of the populations and their habitats, and how discretionary BLM actions affect those species and their habitats."[10] The leasing of federal lands for oil and gas extraction is a discretionary BLM action that has the potential to adversely affect lesser prairie-chicken habitat and prospects for recovery.

Deferring an analysis of the potential effects of selling oil and gas leases to the APD stage is entirely inconsistent with the requirements of Manual 6840. If a lease is sold, the lessee acquires certain contractual rights constraining BLM authority. For example, according to 43 C.F.R. § 3101.1-2, once a lease is issued to its owner, that owner has the "right to use as much of the lease lands as is necessary to explore for, drill for, mine, extract, remove and dispose of the leased resource in the leasehold" subject to specific nondiscretionary statutes and lease stipulations. Therefore, once the lease is sold, it will be too late for BLM to ensure that sufficient protections will be in place to protect this species from the cumulative impacts of extraction-related activities.

Furthermore, pursuant to Manual 6840 Bureau sensitive species are considered BLM special status species, and Section 2 of the Manual provides specific measures that BLM is required to undertake in order to "conserve these species and their habitats."[11] To implement this section, BLM "shall... minimize or eliminate threats" affecting Bureau sensitive species, by determining their current threats and habitat needs, and ensuring that BLM activities "are carried out in a way that is consistent with its objectives for managing those species and their habitats at the appropriate spatial scale."[12] Due to the potential harms from habitat loss and fragmentation, the appropriate spatial scale for determining threats to the lesser praire-chicken from oil and gas development is the entire area subject to lease sales.

The need for a broader analysis to assess the threats to this species from the lease sale itself is further supported by Manual 6840's requirement that BLM work with partners and stakeholders to "develop species-specific or ecosystem-based conservation strategies," and in the absence of such strategies, to incorporate standard operating procedures and other conservation measures "to mitigate specific threats to Bureau sensitive species *during the planning of activities and projects*."[13] Postponing any analysis of impacts to the lesser prairie-chicken until the later APD stage forecloses the implementation of standard procedures and conservation

[8] *Id*. at § .02 (emphasis added).
[9] *Id.* at § .06.
[10] *Id.* at § .04.
[11] *Id.* at § .2 ("All federally designated candidate species, proposed species, and delisted species in the 5 years following their delisting shall be conserved as Bureau sensitive species.").
[12] *Id*. at § .2(C) (emphasis added).
[13] *Id.* (emphasis added).

measures necessary to mitigate threats to the species during exploration or other actions that might take place prior to an APD being filed, since as noted above once a lease is issued, the owner has the "right to use as much of the lease lands as is necessary to explore for, drill for, mine, extract, remove and dispose of the leased resource in the leasehold."[14]

Moreover, the development of species-specific and ecosystem-based conservation strategies implicitly necessitates a more holistic review of the cumulative impacts of the proposed lease sale, which cannot be accomplished through site-specific APD-stage analysis alone. And, piecemeal analyses of individual lease sales do not provide the appropriate perspective for examining the cumulative effects of hydraulic fracturing and climate change impacts at the regional and landscape scale and for making land management decisions.

Where activities have the potential to adversely impact species of concern, the general practice is to consider those impacts and address them "at the earliest possible time," in order to avoid delay, ensure that impacts are avoided and opportunities for mitigation are not overlooked.[15] This is likewise true in the context of even more general environmental review, such as under NEPA.[16] Furthermore, it is general practice to evaluate the impacts of several related projects with cumulative impacts proposed or reasonably foreseeable in the same geographic region in a single, comprehensive, analysis.[17] Likewise, under the ESA an analysis of the effects of an action must consider actions that are interrelated or interdependent.[18] This suggests that BLM should consider the effects of oil and gas extraction activities at the lease sale stage, since those actions are inherent in leasing land for such purposes. It is therefore evident that in order to effectuate the policy of protecting Bureau sensitive species set forth in Manual 6840,[19] and consistent with the established practice of early, comprehensive review of potential impacts to sensitive species, BLM must consider impacts to lesser prairie-chicken at the lease sale, rather than waiting until the APD stage for project specific review.

In sum, BLM has issued regulations in Manual 6840 that require the agency to undertake actions to protect sensitive species, much like they protect proposed and listed species. Delaying an analysis of impacts to lesser prairie-chicken until the APD stage risks harm to an at-risk species that could otherwise be avoided. A failure to address the impacts to lesser prairie-chicken at the lease sale stage violates BLM's own regulations set forth in Manual 6840, is entirely inconsistent with established practice and policies regarding species protection, and is therefore arbitrary and capricious agency action under the Administrative Procedures Act.

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[14] 43 C.F.R. § 3101.1-2.
[15] *See i.e.* 50 C.F.R. §§ 402.14(a), (g)(8).
[16] *See* 40 C.F.R. § 1501.2 ("Agencies shall integrate the NEPA process with other planning at the earliest possible time to insure that planning and decisions reflect environmental values, to avoid delays later in the process, and to head off potential conflicts.").
[17] *See Kleppe v. Sierra Club*, 427 U.S. 390, 410 (1976) ("when several proposals for . . . actions that will have cumulative or synergistic environmental impact upon a region are pending concurrently before an agency, their environmental consequences must be considered together.").
[18] 50 C.F.R. §§ 402.14 and 402.02.
[19] *See* BLM Manual 6840 at .06 ("Bureau sensitive species will be managed consistent with species and habitat management objectives in land use and implementation plans to promote their conservation and to minimize the likelihood and need for listing under the ESA.").

Given the significance of the potential impacts that oil and gas development could have on the species, proper investigation here is crucial. BLM admits that oil and gas production poses several threats to LPC such as reductions in reproductive success, the loss of recruitment into the local population, and habitat fragmentation. The only protective measures BLM sets are a stipulation prohibiting drilling between March 1 and June 15 "in LPC habitat." BLM however does not take into account the impacts to the LPC population and habitat when drilling occurs on suitable habitat. Furthermore, the stipulation prohibits "new drilling" within only 200 meters of leks. BLM claims that requiring lessees to comply with these stipulations will sufficiently "minimize" impacts to LPC. This minimal protection, however, falls short of the oil and gas impact mitigation measures endorsed by the FWS in its 2014 Intra-Service Section 7 Conference Opinion on the Proposed Issuance of a Section 10(a)(1)(A) Enhancement of Survival Permit for Lesser Prairie-Chicken to Western Association of Fish and Wildlife Agencies (Feb. 28, 2014) ("LEPC Oil and Gas Rangewide CCAA Conference Opinion").[20] The CCAA Conference Opinion found that, in order to avoid or minimize adverse impacts,

> [o]il and gas development should avoid high priority LEPC areas, namely focal areas, connectivity zones, and within 1.25 miles of known leks that have been active in the past 5 years, and should instead be focused in lands with existing impacts (e.g. developed oilfields) or cultivation (i.e. row-crops). The conservation measures should also specify that impacts of oil and gas development should be minimized by reducing the area of surface disturbance through directional drilling and clustering of facilities as well as by use of common rights-of-way for infrastructure such as roads, pipelines, and power lines, etc.

CCAA Conference Opinion at 7. Because BLM has a statutory obligations to conserve sensitive species and avoid the necessity for ESA listing, it can and should, in managing the lands entrusted to it under FLPMA, go further than the voluntary measures of the WAFWA CCAA in conditioning oil and gas development on avoiding impacts to LPC suitable habitat. The BLM's proposed stipulation, however, falls short of even those recommendations.

The impact buffers must also apply to more than just well pads. It also must apply to compressor stations, roads, buildings and distribution lines. For larger compressor stations, a 667-meter buffer is recommended. To satisfy the requirements of NEPA and its sensitive species policy, BLM must take a hard look at the area of suitable habitat that will be removed by construction of *all* drilling infrastructure. It is not sufficient to simply conclude that direct impacts will be minimized by merely pointing out that the indirect and cumulative effects of the proposed action may result in lost reproductive potential and corresponding reductions of the chicken population and then imposing inadequate stipulations. The indirect and cumulative effects of habitat loss also must be considered and disclosed.

[20] U.S. Department of Interior Fish and Wildlife Service, Intra-Service Section 7 Conference Opinion on the Proposed Issuance of a Section 10(a)(1)(A) Enhancement of Survival Permit for Lesser Prairie-Chicken to Western Association of Fish and Wildlife Agencies (Feb. 28, 2014) ("LEPC Oil and Gas Rangewide CCAA Conference Opinion").

BLM is required under NEPA to collect data particular to the region affected by the leases.[21] Summarizing general data about LPC before dismissing the issue as insignificant does not provide the "hard look" that NEPA requires.[22] The EA contains insufficient analysis of the impacts to LPC within the CFO. BLM must include discussion of the impacts of oil and gas development on the species, its behavior, survival, and persistence, not just on the impacts of noise to courtship interaction and reproduction.

BLM's conclusion of no significant impact is based on the unreasonable lack of consideration of how fracking could impact the population and habitat of the LPC on and surrounding the parcels that are being offered for lease sale, and is therefore arbitrary and capricious.

b. BLM Does Not Take a Hard Look at Impacts to Water Resources

The EA briefly mentions some of the inevitable impacts that oil and gas development will have on water resources, including contamination and degradation of surface water and groundwater quality, loss of drilling fluids (which contain harmful chemicals), reduction in natural flow of seeps, springs, and water wells.[23] BLM then dismisses these concerns as insignificant with no explanation other than the claim that "specific mitigation measures for the protection of surface and ground water would be addressed at the APD stage,"[24] and then briefly lists a few examples of what mitigation "may include." As we have explained above, mitigation measures cannot form the basis of a finding of no significant impact without meeting at least some minimal standards. Wyo. Outdoor Council, 351 F. Supp. 2d at 1250 (D. Wyo. 2005). For example, the mitigation measures must be more than a possibility. Id. ("They must be imposed by statute or regulation or have been so integrated into the initial proposal that it is impossible to define the proposal without the mitigation."); see also Davis v. Mineta, 302 F.3d 1104, 1125 (10th Cir. 2002) (overturning the finding of no significant impact because "the [EA] makes no firm commitment to any noise mitigation measures.").

The EA fails to adequately analyze site-specific impacts, again deferring the required analysis to the APD review stage.[25] As BLM acknowledges, "[f]resh water is a scarce resource in the CFO" and fourteen of the proposed parcels are within or near known playas, streams, rivers, floodplains, springs, seeps, or dirt tanks. BLM further acknowledges that large volumes of water are needed for hydraulic fracturing and that the use of groundwater could result in the drawdown of groundwater aquifer levels. BLM explains that the magnitude of any of these described impacts to water resources would depend on several factors including slope, aspect, and gradient, soil character, and proximity of disturbance to water resources. The EA could have, and should have, provided site-specific analysis based on information regarding the

[21] See *Center for Biological Diversity v. Bureau of Land Management*, 937 F. Supp. 2d (2013) at 1159 (Preparation of an EIS "is mandated where uncertainty may be resolved by further collection of data, or where collection of such data may prevent speculation on potential effects.").
[22] *Id*. (Held BLM did not provide the "hard look" that NEPA requires because it "never collected any data particular to the region affected by the leases, instead opting to summarize general data.").
[23] EA at 42.
[24] *Id*.
[25] EA at 42.

characteristics of the area to be leased that may be affected by the oil and gas development on these parcels. Regardless, given the high degree of uncertainty in the severity of harm that oil and gas development could have on the water resources in the areas for lease, BLM is required to prepare an EIS. See Babbitt, 241 F.3d at 732 (Preparation of an EIS is "mandated where uncertainty may be resolved by further collection of data" or where the collection of such data may prevent speculation on potential effects.)

BLM does not address *any* specific mitigation measures for the protection of surface and ground water at this point. Instead, BLM writes that such measures will be addressed after it has already signed over drilling rights and is unable to preclude all surface disturbing activities to prevent critical environmental impacts that may arise after a proper NEPA analysis. Nor does BLM provide any science or any evidence to support its finding of no significant impact. In our previous comment letters, we cited to numerous well-researched, scientific studies showing the foreseeable impacts that BLM's actions may pose to the water resources in the areas to be leased, some of which BLM admits are indeed potential impacts. However, rather than set the necessary safeguards or take the required hard look at the problem, BLM looks the other way by declining to prepare an EIS.

Although BLM set a stipulation for a minimum 200-meter buffer from the edge of the floodplain or wetland, to be applied to an APD, there is no science cited by BLM to support the notion that this is sufficient protection. If BLM relies upon mitigation measures as the basis for its finding of no significant impact, BLM must show that such mitigation measures "constitute an 'adequate buffer' . . . so as to 'render such impacts so minor as to not warrant an EIS.'" Wyo. Outdoor Council, 351 F. Supp. 2d at 1250. However, the EA does not provide *any* evidence of the adequacy of the vague mitigation measures proposed, let alone the "substantial" evidence necessary to reduce environmental impacts below the level of significance that would require an EIS. Id. Again, the lack of supporting data and cursory treatment of environmental effects in EA does not support BLM's refusal to produce an EIS. Babbitt, 241 F.3d at 732.

c. BLM Does Not Take a Hard Look at Impacts of Fracking on Air Quality, Water Resources, Soil, Vegetation, or Wildlife

Although we raised various concerns about other unconventional and controversial practices in scoping and in our comments on the PEA, such as horizontal drilling, the Final EA only discusses hydraulic fracturing. According to the EA, "it is anticipated that with more wells being drilled, there would be an increase in the amount of wells being hydraulically fractured and completed."[26] Despite the likelihood of hydraulic fracturing occurring on the parcels to be leased, and the severity of the impacts that would ensue from such controversial practices, BLM provides hardly any analysis on said impacts. BLM only briefly mentions the impacts of hydraulic fracturing on air quality, water resources, soil, sensitive species, and vegetation. The EA does not include any analysis of the other concerns relating to fracking that we raised, such as induced seismicity, especially with respect to sinkholes, or the WIPP.

[26] EA at 35.

BLM's mention of the impacts of hydraulic on air quality are insufficient. For instance, the EA raises the problem of "flowback" and "venting and flaring" but does not set any mitigation measures for these concerns. Indeed it admits that:

> While federal regulations require that hydraulically fractured gas wells employ "Reduced Emission Completion" (REC) techniques to avoid the venting and flaring of gas, oil wells are not required to use REC techniques. Although REC techniques can be applied to oil well completions, natural gas has typically been vented to the atmosphere or flared while fracturing fluids that include sand, water, and other liquids are directed into holding tanks.[27]

The EA also raises the issue of volatile organic compounds ("VOCs"), particulate matter, and NO2, which contribute to the formation of ozone, but does not provide any analysis of their impacts on the environment, public health, or wildlife resources. The EA further acknowledges that flowback, fracturing fluids, water and reservoir gas return to the surface at high velocity and volume and that mixture includes a high volume of VOCs and methane, along with potential air toxics such as benzene, ethylbenzene, and n-hexane. Without citing to any supporting data, studies, or any scientific evidence, BLM then concludes that impacts to human health are not anticipated. BLM then admits that there is great uncertainty in the quantity of harmful emissions and resulting public risks, "[d]ue to differences in the quantities and concentrations of fracturing chemicals used, to the lack of maximum contaminant levels or thresholds for them, and to the possibility of chemical reactions during the mixing of hydraulic fracturing fluids."[28] As we have already asserted above, preparation of an EIS is required where uncertainty may be resolved by further collection of data or where the collection of such data may prevent speculation on potential effects. Babbitt, 241 F.3d at 732. Here, BLM has not collected any data, instead relying only upon RMPs that are decades old for the required analysis. Further cementing its failures as to NEPA, BLM once again fails to set any actual mitigation measures. Instead the EA only states that BLM "encourages" industry to incorporate and implement BMPs, and then briefly lists what "typical measures" might include.[29]

BLM's analysis of the impacts of hydraulic fracturing on water resources are similarly deficient. The EA raises only a few of the concerns we brought up in scoping and in our comments on the PEA:

> Potential causes of impacts to water resources from drilling operations include the loss of drilling fluids, which sometimes contain heavy metals and other chemicals, or cement. This may pollute groundwater recharge areas and adversely impact water quality. Additionally, cementing operations could plug some of the underground drainages and restrict groundwater flow, thereby reducing the recharge quality and quantity of springs, resurgences, and water tables and reducing the natural flow from seeps, springs, and water wells. In addition, drilling an oil or gas well may require large quantities of water, especially when drilling through porous and permeable formations. Fresh water is a scarce resource in the CFO and depending on the source used, natural flow from seeps,

[27] EA at 35-36.
[28] EA at 36.
[29] EA at 36.

springs, and water wells could be reduced . . . . There also is the potential for illegal dumping of waste products into fresh water pits used during the hydraulic fracturing purposes. If this illegal dumping was to occur there is the potential to impact migratory birds and other wildlife species.[30]

The potential impacts listed in this paragraph, alone, are significant enough to warrant an EIS. The EA also does not attach any safeguards or stipulations to the proposed action that would reduce these impacts to a minimum, nor does it provide any analysis or evidence to support a finding of no significant impact. BLM fails to discuss any set mitigation measures. Again refusing to fulfill its mandatory obligations under NEPA, BLM defers the required site specific analysis and addressing specific mitigation measures to the APD stage.[31] These same deficiencies apply to the EA's treatment of the potential impacts of hydraulic fracturing on soil, vegetation, wildlife and wildlife resources.

d. BLM Does Not Take a Hard Look at Impacts of Fracking in Light of Risks of Induced Seismicity, Brine Well Collapses, and Releases of Radionuclide Waste into the Biosphere

Perhaps most concerning is BLM's utter disregard of the public health and safety risks associated with induced seismicity, especially in the face of seismic data at and near the Waste Isolation Pilot Plant ("WIPP"), a facility of the U.S. Department of Energy ("DOE") designed and constructed for the permanent disposal of transuranic (TRU) defense waste.[32] Over the past 15 years, the WIPP has become the storage site for over 91,000 cubic meters of such radioactive waste, which includes laboratory equipment and clothing and residual chemical waste from U.S. nuclear weapons projects.[33] The WIPP storage facilities are 655 m underground in 600-meter-thick bedded salt formations in the Delaware Basin.[34] The transuranic waste is stored in plastic-lined steel drums within these underground storage sites. This bedded salt formation is the major geologic barrier for radionuclide leakage at the WIPP site.[35]

These same salt layers are drilled through to extract underlying oil and gas.[36] Drilling fluids pre-saturated with salt (brine) is required in the drilling process. A "brine well" is a solution mining operation to remove salt. Fresh water is introduced into the subsurface through a well casing, thereby dissolving the salt. The brine is then pumped out and trucked to wellsites.[37] The solution mining of the salt results in an underground cavern; the stability of these caverns is dependent upon their depth, their width, and the strength of the materials above the void.[38] Since July of 2008, three large sinkholes associated with brine wells in the Permian Basin have

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[30] EA at 42.
[31] EA at 42-43.
[32] Silva, M.K., Fluid Injection for Salt Water Disposal and Enhanced Oil Recovery as a Potential Problem for the WIPP: Proceedings of a June 1995 Workshop and Analysis ("EEG-62 Salt Water Disposal") (1996) at xiv.
[33] Tracy, C. L. et al., Policy: Reassess New Mexico's Nuclear-Waste Repository, 529 Nature 149 (2016).
[34] Beauheim , R. L. and R. M. Roberts, Hydrology and hydraulic properties of a bedded evaporite formation, 259 J. Hydrol. 66 (2002).
[35] *Id.*
[36] State of New Mexico Oil Conservation Division, Brine Well Information, http://www.emnrd.state.nm.us/OCD/brinewellinfo.html (accessed May 20, 2016).
[37] *Id.*
[38] *Id.*

catastrophically developed, two of which are located in New Mexico. Within days of the first brine well collapse southeast of Artesia on July 16, 2008, division personnel became concerned about an oilfield trucking operation in Carlsbad which incorporated an active brine well of similar depth and production history.[39] This facility is located amidst two major roadways, a vital irrigation canal, a trailer park, a church, and a feed store. On November 3, 2008 the second brine cavern collapse occurred north of Loco Hills and a moratorium on new brine wells was put into effect. In 2009, a gathering of regulators, technical experts, and industry was held to discuss overall brine well safety during which a consensus developed that the brine cavern in Carlsbad had a high probability for collapse.[40] Therefore, the practices of hydraulic fracturing not only increase the risks of earthquakes, but also the catastrophic collapse of these brine caverns.

The EA briefly discusses in general "cave and karst features" along with several potential impacts relating to drilling and development near such features. Some of these concerns that the EA brings up include the disruption, displacement, or extermination of cave species and critical biological processes; the contamination of underground water systems and freshwater aquifers; underground ignitions or asphyxiation of wildlife or humans within these caves (due to buildup of hydrocarbons from surface leaks or spills); as well as adverse impacts to cave ecosystems and aquifer recharge processes from blasting which can lead to changes in geologic formation integrity, runoff quantity and quality, drainage course, rainfall percolation factors, vegetation, surface contour, and other surface factors, collapse of subsurface voids, or cave ecosystem damage. BLM addresses all of these concerns in one brief sentence about what the potential mitigations that could be developed during the APD and lease development stages "may include," as well as a highly speculative and conclusory statement that the stipulation (prohibiting surface occupancy within 200 meters of any known cave or karst feature or system) "would minimize any potential impacts to the resource."[41] BLM once again does not cite to any studies, data, or a shred of evidence to show that the stipulation would be enough to protect the environment and human health and safety from the aforementioned concerns.

The same failure can be said of BLM's glaring omission with respect to the threats associated with drilling near the WIPP. In selecting a repository site, the Los Medanos site in Eddy County was ultimately chosen, relying in part on the conclusion that there were no oil reserves at the site.[42] For oil field operations, the problem of water migrating from the injection zone, through other formations, and onto adjacent property has long been recognized. However, the DOE relinquished the right to restrict waterflooding based on a natural resources report which maintained that there was a minimal amount of crude oil likely to exist at the WIPP site. [43] In the early 1990s, the Delaware Basin experienced a drilling boom that included oil field discoveries surrounding and underlying the WIPP Site.[44] Salt water disposal wells began operating throughout the area in the mid to late 1990s, and waterflooding began with new oil field pressure maintenance programs underway.[45] Brine migration, driven by pressure, is the same mechanism by which radionuclides can be carried out of the repository and away from the

[39] *Id.*
[40] *Id.*
[41] EA at 54.
[42] EEG-62 Salt Water Disposal at xiv.
[43] *Id.*
[44] *Id.*
[45] *Id.*

WIPP site.[46] The dangerous practices of hydraulic fracturing and similar unconventional extract techniques therefore increase the risks of radionuclide waste leakage.

Furthermore, and as we have already explained in previous letters, the underground injection processes involved in unconventional oil and gas development has been associated with earthquakes in several locations. Research has shown that in regions of the central and eastern United States where unconventional oil and gas development has proliferated in recent years, earthquake activity has increased dramatically.[47] Research has also linked much of the increased earthquake activity and several of the largest earthquakes in the U.S. midcontinent in recent years to the disposal of wastewater into deep injection wells, which is well-established to pose a significant seismic risk.[48] Much of the fracking wastewater is a byproduct of oil and gas production and is routinely disposed of by injection into wells specifically designed and approved for this purpose. The injected fluids push stable faults past their tipping points, and thereby induce earthquakes.[49] In 2015, a study published in *Science* found that, the unprecedented increase in earthquakes in the U.S. mid-continent began in 2009 has been caused by the instability caused by fluid injection wells associated with fracking waste disposal.[50]

There has been significant oil and gas drilling near the WIPP site, which has been increasing in recent years. Advances in hydraulic fracturing and other unconventional extraction techniques have allowed the oil and gas industry to access new regions of hydrocarbon-bearing rocks, making the Permian Basin one of the largest hydrocarbon-rich areas in the U.S. The DOE calculates more than more than 500 oil and gas wells within 2.5 miles of the WIPP boundary.[51] As more and more boreholes are drilled in the nearby region, it increases the likelihood that one of them may lead to leakage of the stored transuranic waste. Thus the proliferation of unconventional oil and gas development, including increases in extraction and injection, will increase not only earthquake risks in the CFO and Pecos District planning area, but also risks of releasing contamination into the surrounding biosphere. The WIPP is the only transuranic waste depository in the U.S. and plays a key role in managing the waste generated from nuclear weapon defense projects.[52] Human intrusion into the region through oil drilling can be expected to compromise the integrity of the natural barriers protecting the public and environment from the dangerous radionuclide waste.

The scope of harm that could result from any release of high level tranuranic waste is exceptionally great, and thus requires an extensive look at the potential impacts to the human

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[46] *Id.* at 16.
[47] *Id.*
[48] *Id.*
[49] Lamont-Doherty Earth Observatory, Distant Quakes Trigger Tremors at U.S. Waste-Injection Sites, Says Study, Columbia University (July 11, 2013), https://www.ldeo.columbia.edu/news-events/distant-quakes-trigger-tremors-us-waste-injection-sites-says-study (accessed May 20, 2016).
[50] Weingarten, M. et al., High-rate injection is associated with the increase in U.S. mid-continent seismicity, 348 Science 6241:1336 (2015).
[51] U. S. Environmental Protection Agency, Response to Comments on Completeness Regarding the 2014 WIPP Compliance Recertification Application (June 16, 2015) at 26-27, *available at* https://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2014-0609-001. *See* Map, Figure 3.
[52] U.S. Department of Energy, Transuranic (TRU) Waste, http://energy.gov/em/services/waste-management/waste-and-materials-disposition-information/transuranic-tru-waste (accessed May 20, 2016).

environment. Because of the high degree of uncertainty and the substantial controversy regarding the possible effects of such disasters, BLM is required to prepare an EIS.

B. BLM Must End All New Fossil Fuel Leasing and Hydraulic Fracturing.

The following discussion updates the Center's previous request for no new leasing and fracking in CFO and Pecos District area, in light of new information that has arisen since the EA comment period.

Climate change is a problem of global proportions resulting from the cumulative greenhouse gas emissions of countless individual sources. A comprehensive look at the impacts of fossil fuel extraction, and especially fracking, across all of the planning areas affected by the leases in updated RMPs is absolutely necessary. BLM has *never* thoroughly considered the cumulative climate change impacts of *all* potential fossil fuel extraction and fracking (1) within each of the planning areas, (2) across the state, and (3) across all public lands. Proceeding with new leasing proposals *ad hoc* in the absence of a comprehensive plan that addresses climate change and fracking is premature and risks irreversible damage before the agency and public have had the opportunity to weigh the full costs of oil and gas and other fossil fuel extraction and consider necessary limits on such activities. Therefore BLM must cease all new leasing at least until the issue is adequately analyzed in a programmatic review of all U.S. fossil fuel leasing, or at least within amended RMPs.

i. BLM Must Limit Greenhouse Gas Emissions By Keeping Federal Fossil Fuels In the Ground

Expansion of fossil fuel production will substantially increase the volume of greenhouse gases emitted into the atmosphere and jeopardize the environment and the health and well being of future generations. BLM's mandate to ensure "harmonious and coordinated management of the various resources *without permanent impairment of the productivity of the land and the quality of the environment*" requires BLM to limit the climate change effects of its actions.[53] Keeping all unleased fossil fuels in the ground and banning fracking and other unconventional well stimulation methods would lock away millions of tons of greenhouse gas pollution and limit the destructive effects of these practices.

A ban on new fossil fuel leasing and fracking is necessary to meet the U.S.'s greenhouse gas reduction commitments. On December 12, 2015, 197 nation-state and supra-national organization parties meeting in Paris at the 2015 United Nations Framework Convention on Climate Change Conference of the Parties consented to an agreement (Paris Agreement) committing its parties to take action so as to avoid dangerous climate change. [54] As the Paris

[53] *See* 43 U.S.C. §§ 1701(a)(7), 1702(c), 1712(c)(1), 1732(a) (emphasis added); *see also id.* § 1732(b) (directing Secretary to take any action to "prevent unnecessary or undue degradation" of the public lands).
[54] United Nations Framework Convention on Climate Change, Adoption of the Paris Agreement, Proposal by the President, Draft decision -/CP.21 (2015) ("Paris Agreement") at Art. 2.

Agreement opens for signature in April 2016[55] and the United States is expected to sign the treaty[56] as a legally binding instrument through executive agreement,[57] the Paris Agreement commits the United States to critical goals—both binding and aspirational—that mandate bold action on the United States' domestic policy to rapidly reduce greenhouse gas emissions.[58]

The United States and other parties to the Paris Agreement recognized "the need for an effective and progressive response to the urgent threat of climate change on the basis of the best available scientific knowledge."[59] The Paris Agreement articulates the practical steps necessary to obtain its goals: parties including the United States have to "reach global peaking of greenhouse gas emissions *as soon as possible* . . . and to *undertake rapid reductions* thereafter in accordance *with best available science*,"[60] imperatively commanding that developed countries specifically "should continue taking the lead by undertaking economy-wide absolute emission reduction targets"[61] and that such actions reflect the "highest possible ambition."[62]

The Paris Agreement codifies the international consensus that climate change is an "urgent threat" of global concern,[63] and commits all signatories to achieving a set of global goals. Importantly, the Paris Agreement commits all signatories to an articulated target to hold the long-term global average temperature "to *well below 2°C* above pre-industrial levels and to *pursue efforts to limit the temperature increase to 1.5°C* above pre-industrial levels"[64] (emphasis added).

In light of the severe threats posed by even limited global warming, the Paris Agreement established the international goal of limiting global warming to 1.5°C above pre-industrial levels in order to "prevent dangerous anthropogenic interference with the climate system," as set forth in the UNFCCC, a treaty which the United States has ratified and to which it is bound.[65] The Paris consensus on a 1.5°C warming goal reflects the findings of the IPCC and numerous scientific studies that indicate that 2°C warming would exceed thresholds for severe, extremely

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[55] Paris Agreement, Art. 20(1).
[56] For purposes of this Petition, the term "treaty" refers to its international law definition, whereby a treaty is "an international law agreement concluded between states in written form and governed by international law" pursuant to article 2(a) of the Vienna Convention on the Law of Treaties, 1155 U.N.T.S. 331, 8 I.L.M. 679 (Jan. 27, 1980).
[57] *See* U.S. Department of State, Background Briefing on the Paris Climate Agreement, (Dec. 12, 2015), http://www.state.gov/ r/pa/prs/ps/2015/12/250592.htm.
[58] Although not every provision in the Paris Agreement is legally binding or enforceable, the U.S. and all parties are committed to perform the treaty commitments in good faith under the international legal principle of *pacta sunt servanda* ("agreements must be kept"). Vienna Convention on the Law of Treaties, Art. 26.
[59] *Id.*, Recitals.
[60] *Id.*, Art. 4(1).
[61] *Id.*, Art. 4(4).
[62] *Id.*, Art. 4(3).
[63] *Id.*, Recitals.
[64] *Id.*, Art. 2.
[65] *See* U.N. Framework Convention on Climate Change, Cancun Agreement (2011), *available at* http://cancun.unfccc.int/ (last visited Jan 7, 2015); United Nations Framework Convention on Climate Change, Copenhagen Accord (2009), *available at* http://unfccc.int/meetings/copenhagen_dec_2009/items/5262.php (last accessed Jan 7, 2015). The United States Senate ratified the UNFCC on October 7, 1992. *See* U.S. Congress, Ratification of Treaty Document titled The United Nations Framework Convention on Climate Change, adopted May 9, 1992 *available at* https://www.congress.gov/treaty-document/102nd-congress/38.

dangerous, and potentially irreversible impacts.[66] Those impacts include increased global food and water insecurity, the inundation of coastal regions and small island nations by sea level rise and increasing storm surge, complete loss of Arctic summer sea ice, irreversible melting of the Greenland ice sheet, increased extinction risk for at least 20-30% of species on Earth, dieback of the Amazon rainforest, and "rapid and terminal" declines of coral reefs worldwide.[67] As scientists noted, the impacts associated with 2°C temperature rise have been "revised upwards, sufficiently so that 2°C now more appropriately represents the threshold between 'dangerous' and 'extremely dangerous' climate change."[68] Consequently, a target of 1.5 ºC or less temperature rise is now seen as essential to avoid dangerous climate change and has largely supplanted the 2°C target that had been the focus of most climate literature until recently.

Immediate and aggressive greenhouse gas emissions reductions are necessary to keep warming below a 1.5º or 2°C rise above pre-industrial levels. Put simply, there is only a finite amount of CO_2 that can be released into the atmosphere without rendering the goal of meeting the 1.5°C target virtually impossible. A slightly larger amount could be burned before meeting a 2°C became an impossibility. Globally, extracting and burning all proven fossil fuel reserves would release enough CO_2 to exceed this limit many times over.[69] This is before accounting for unproven resources, such as would be targeted under any new BLM leasing.

The question of what amount of fossil fuels can be extracted and burned without negating a realistic chance of meeting a 1.5 or 2°C target is relatively easy to answer, even if the answer is framed in probabilities and ranges. The IPCC Fifth Assessment Report and other expert assessments have established global carbon budgets, or the total amount of remaining carbon that can be burned while maintain some probability of staying below a given temperature target. According to the IPCC, total cumulative anthropogenic emissions of CO_2 must remain below about 1,000 gigatonnes ($GtCO_2$) from 2011 onward for a 66% probability of limiting warming to 2°C above pre-industrial levels.[70] Given more than 100 $GtCO_2$ have been emitted since 2011,[71]

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[66] *See* Paris Agreement, Art. 2(1)(a); U); United Nations Framework Convention on Climate Change, Subsidiary Body for Scientific and Technical Advice, Report on the structured expert dialogue on the 2013-15 review, No. FCCC/SB/2015/INF.1 at 15-16 (June 2015); Intergovernmental Panel on Climate Change, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change at 64 & Table 2.2 [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)] ("IPCC AR5 Synthesis Report") at 65 & Box 2.4.

[67] *See* Jones, C. et al, Committed Terrestrial Ecosystem Changes due to Climate Change, 2 Nature Geoscience 484: 484–487 (2009); Smith, J. B. et al., Assessing Dangerous Climate Change Through an Update of the Intergovernmental Panel on Climate Change (IPCC) 'Reasons for Concern', 106 Proceedings of the National Academy of Sciences of the United States of America 4133 (2009); Veron, J. E. N. *et al.*, The Coral Reef Crisis: The Critical Importance of <350 ppm CO2, 58 Marine Pollution Bulletin 1428, (2009); Warren, R. J. *et al.*, Increasing Impacts of Climate Change Upon Ecosystems with Increasing Global Mean Temperature Rise, 106 Climatic Change 141 (2011); Hare, W. W. *et al.*, Climate Hotspots: Key Vulnerable Regions, Climate Change and Limits to Warming, 11 Regional Environmental Change 1 (2011); Frieler, K. M. *et al.*, Limiting Global Warming to 2ºC is Unlikely to Save Most Coral Reefs, Nature Climate Change, Published Online (2013) doi: 10.1038/NCLIMATE1674; Schaeffer, M. *et al.*, Adequacy and Feasibility of the 1.5°C Long-Term Global Limit, Climate Analytics (2013).

[68] Anderson, K. and A. Bows, Beyond 'Dangerous' Climate Change: Emission Scenarios for a New World, 369 Philosophical Transactions, Series A, Mathematical, Physical, and Engineering Sciences 20 (2011).

[69] Cimons, Marlene, Keep It In the Ground 6, Sierra Club *et al.* (Jan. 25, 2016).

[70] IPCC, 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Summary for Policymakers (2013) at 27; IPCC AR5 Synthesis Report.

the remaining portion of the budget under this scenario is well below 900 $GtCO_2$. To have an 80% probability of staying below the 2°C target, the budget from 2000 is 890 $GtCO_2$, with less than 430 $GtCO_2$ remaining.[72]

To have even a 50% probability of achieving the Paris Agreement goal of limiting warming to 1.5°C above pre-industrial levels equates to a carbon budget of 550-600 $GtCO_2$ from 2011 onward, [73] of which more than 100 $GtCO_2$ has already been emitted. To achieve a 66% probability of limiting warming to 1.5°C requires adherence to a more stringent carbon budget of only 400 $GtCO_2$ from 2011 onward, [74] of which less than 300 $GtCO_2$ remained at the start of 2015.[75] An 80% probability budget for 1.5°C would have far less that 300 $GtCO_2$ remaining. Given that global CO_2 emissions in 2014 alone totaled 36 $GtCO_2$,[76] humanity is rapidly consuming the remaining burnable carbon budget needed to have even a 50/50 chance of meeting the 1.5°C temperature goal.[77]

According to a recent report by EcoShift Consulting commissioned by the Center and Friends of the Earth, unleased (and thus unproven and unburnable) federal fossil fuels represent a significant source of potential greenhouse gas emissions:

- Potential GHG emissions of federal fossil fuels (leased and unleased) if developed would release up to 492 gigatons (Gt) (one gigaton equals 1 billion tons) of carbon dioxide equivalent pollution (CO2e); representing 46 percent to 50 percent of potential emissions from all remaining U.S. fossil fuels.
- Of that amount, up to 450 Gt CO2e have not yet been leased to private industry for extraction;
- Releasing those 450 Gt CO2e (the equivalent annual pollution of more than 118,000 coal-fired power plants) would be greater than any proposed U.S. share of global carbon limits that would keep emissions below scientifically advised levels.

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[71] From 2012-2014, 107 GtCO2 was emitted (*see* Annual Global Carbon Emissions at http://co2now.org/Current-CO2/CO2-Now/global-carbon-emissions.html (accessed May 20, 2016)).

[72] Carbon Tracker Initiative, Unburnable Carbon – Are the world's financial markets carrying a carbon bubble? http://www.carbontracker.org/wp-content/uploads/2014/09/Unburnable-Carbon-Full-rev2-1.pdf (accessed May 20, 2016); Meinshausen, M. *et al.*, Greenhouse gas emission targets for limiting global warming to 2 degrees Celsius, 458 Nature 1158, 1159 (2009).

[73] IPCC AR5 Synthesis Report at 64 & Table 2.2.

[74] *Id*.

[75] See CarbonBrief, Carbon Countdown: How Many Years of Current Emissions Would Use up the IPCC's Carbon Budgets for Different Levels of Warming, http://www.carbonbrief.org/analysis-only-five-years-left-before-one-point-five-c-budget-is-blown (accessed May 20, 2016).

[76] *See* Global Carbon Emissions, http://co2now.org/Current-CO2/CO2-Now/global-carbon-emissions.html

[77] In addition to limits on the *amount* of fossil fuels that can be utilized, emissions pathways compatible with a 1.5 or 2°C target also have a significant temporal element. Leading studies make clear that to reach a reasonable likelihood of stopping warming at 1.5° or even 2°C, global CO2 emissions must be phased out by mid-century and likely as early as 2040-2045. *See, e.g.* Rogelj, Joeri *et al.*, Energy system transformations for limiting end-of-century warming to below 1.5°C, 5 Nature Climate Change 519, 522 (2015). United States focused studies indicate that we must phase out fossil fuel CO2 emissions even earlier—between 2025 and 2040—for a reasonable chance of staying below 2ºC. *See, e.g.* Climate Action Tracker, http://climateactiontracker.org/countries/usa. Issuing new legal entitlements to explore for and extract federal fossil fuels for decades to come is wholly incompatible with such a transition.

Fracking has also opened up vast resources that otherwise would not be available, increasing the potential for future greenhouse gas emissions. In recognition of established climate science, and global carbon budgeting, BLM must consider a ban on fracking and a ban on new leasing.

Beginning the phase-out of public fossil fuel production by ceasing new onshore leases would have a significant effect on U.S. contributions to greenhouse gas emissions, allowing us to meet targets under the Paris Agreement. The first systematic quantitative assessment of the emissions consequences of a cessation of federal leasing (both onshore and offshore) found that:

> [U]nder such a policy, U.S. coal production would steadily decline, moving closer to a pathway consistent with a global 2°C temperature limit. Oil and gas extraction would drop as well, but more gradually, as federal lands and waters represent a smaller fraction of national production, and these resources take longer to develop. Phasing out federal leases for fossil fuel extraction could reduce global CO2 emissions by 100 million tonnes per year by 2030, and by greater amounts thereafter.[78]

ii. BLM Must Consider A Ban on New Oil and Gas Leasing and Fracking in a Programmatic Review and Halt All New Leasing and Fracking in the Meantime.

Development of unleased oil and gas resources will not only worsen climate disruption, it will undercut the needed transition to a clean energy economy. As BLM has not yet had a chance to consider no leasing and no-fracking alternatives as part of any of its RMP planning processes or a comprehensive review of its federal oil and gas leasing program, BLM should suspend new leasing until it properly considers this alternative in updated RMPs or a programmatic EIS for the entire leasing program. BLM demonstrably has tools available to consider the climate consequences of its leasing programs, and alternatives available to mitigate those consequences, at either a regional or national scale.[79]

BLM would be remiss to continue leasing when it has never stepped back and taken a hard look at this problem at the programmatic scale. Before allowing more oil and gas extraction in the planning area, BLM must: (1) comprehensively analyze the total greenhouse gas emissions which result from past, present, and potential future fossil fuel leasing and all other activities across all BLM lands and within the various planning areas at issue here, (2) consider their cumulative significance in the context of global climate change, carbon budgets, and other greenhouse gas pollution sources outside BLM lands and the planning area, and (3) formulate

[78] Erickson, Peter and Michael Lazarus, How Would Phasing Out U.S. Federal Leases for Fossil Fuel Extraction Affect CO_2 Emissions and 2°C Goals? 1, 31-32, Stockholm Environment Institute Working Paper 2016-02 (May 2016).

[79] *See, e.g.,* U.S. Bureau of Land Management Montana, North Dakota and South Dakota, Climate Change Supplementary Information Report (updated Oct. 2010) (conducting GHG inventory for BLM leasing in Montana, North Dakota and South Dakota); U.S. Bureau of Land Management, Proposed Rule: Waste Prevention, Production Subject to Royalties, and Resource Conservation, 81 Fed. Reg. 6615 (Feb. 8, 2016) (proposing BLM-wide rule for prevention of methane waste).

measures that avoid or limit their climate change effects. By continuing leasing and allowing new fracking in the absence of any overall plan addressing climate change BLM is effectively burying its head in the sand.

A programmatic review and moratorium on new leasing would be consistent with the Secretary of Interior's recent order to conduct a comprehensive, programmatic EIS (PEIS) on its coal leasing program, in light of the need to take into account the program's impacts on climate change, among other issues, and "the lack of any recent analysis of the Federal coal program as a whole." *See* Secretary of Interior, Order No. 3338, § 4 (Jan. 15, 2016). Specifically, the Secretary directed that the PEIS "should examine how best to assess the climate impacts of continued Federal coal production and combustion and how to address those impacts in the management of the program to meet both the Nation's energy needs and its climate goals, as well as how best to protect the public lands from climate change impacts." *Id*. § 4(c).

The Secretary also ordered a moratorium on new coal leasing while such a review is being conducted. The Secretary reasoned:

> Lease sales and lease modifications result in lease terms of 20 years and for so long thereafter as coal is produced in commercial quantities. Continuing to conduct lease sales or approve lease modifications during this programmatic review risks locking in for decades the future development of large quantities of coal under current rates and terms that the PEIS may ultimately determine to be less than optimal. This risk is why, during the previous two programmatic reviews, the Department halted most lease sales with limited exceptions…. Considering these factors and given the extensive recoverable reserves of Federal coal currently under lease, I have decided that a similar policy is warranted here. A pause on leasing, with limited exceptions, will allow future leasing decisions to benefit from the recommendations that result from the PEIS while minimizing any economic hardship during that review.

Id. § 5.

The Secretary's reasoning is also apt here. A programmatic review assessing the climate change effects of public fossil fuels is long overdue. And there is no shortage of oil and gas supply that would preclude a moratorium while such a review is conducted, as evidenced by very low natural oil and gas prices. More importantly, BLM should not "risk[] locking in for decades the future development of large quantities of [fossil fuels] under current…terms that a [programmatic review] may ultimately determine to be less than optimal." *Id*. BLM should cancel the sale and halt all new leasing and fracking until a programmatic review is completed.

C. BLM Must Study the Greenhouse Gas Impacts of New Leasing

As explained in the Center's comment on the PEA, social cost of carbon analysis is an appropriate tool for analyzing the cumulative impacts of greenhouse gas emissions, which the EA inexplicably fails to perform and BLM's response to comments fails to address. The effects of cumulative greenhouse gas emissions will have far-reaching impacts on natural and social

systems, but the EA fails to provide any meaningful analysis of the proposed action's contribution to these effects.

i. The Effects of Cumulative GHG Emissions Will Inflict Extraordinary Harm to Natural Systems and Communities

The Paris Agreement codified the international consensus that the climate crisis is an urgent threat to human societies and the planet, with the parties recognizing that:

> Climate change represents an *urgent and potentially irreversible threat to human societies and the planet* and thus requires the widest possible cooperation by all countries, and their participation in an effective and appropriate international response, with a view to accelerating the reduction of global greenhouse gas emissions (emphasis added).[80]

Numerous authoritative scientific assessments have established that climate change is causing grave harms to human society and natural systems, and these threats are becoming increasingly dangerous. The Intergovernmental Panel on Climate Change (IPCC), in its 2014 Fifth Assessment Report, stated that: "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased" and that "[r]ecent climate changes have had widespread impacts on human and natural systems."[81]

The 2014 Third National Climate Assessment, prepared by a panel of non-governmental experts and reviewed by the National Academy of Sciences and multiple federal agencies similarly stated that "[t]hat the planet has warmed is 'unequivocal,' and is corroborated though multiple lines of evidence, as is the conclusion that the causes are very likely human in origin"[82] and "[i]mpacts related to climate change are already evident in many regions and are expected to become increasingly disruptive across the nation throughout this century and beyond."[83] The United States National Research Council similarly concluded that: "[c]limate change is occurring, is caused largely by human activities, and poses significant risks for—and in many cases is already affecting—a broad range of human and natural systems."[84]

The IPCC and National Climate Assessment further decisively recognize the dominant role of fossil fuels in driving climate change:

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[80] Paris Agreement, Decision, Recitals.
[81] IPCC AR5 Synthesis Report at 2.
[82] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., Climate Change Impacts in the United States: The Third National Climate Assessment (U.S. Global Change Research Program), doi:10.7930/J0Z31WJ2 (2014) ("Third National Climate Assessment") at 61 (quoting IPCC, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, Eds., Cambridge University Press (2007).
[83] Third National Climate Assessment at 10.
[84] National Research Council, Advancing the Science of Climate Change (2010), available at www.nap.edu. ("Advancing the Science of Climate Change") at 2.

> While scientists continue to refine projections of the future, observations unequivocally show that climate is changing and that the warming of the past 50 years is primarily due to human-induced emissions of heat-trapping gases. These emissions come mainly from burning coal, oil, and gas, with additional contributions from forest clearing and some agricultural practices.[85]
> ***
>
> CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% to the total GHG emission increase between 1970 and 2010, with a contribution of similar percentage over the 2000–2010 period (*high confidence*).[86]

These impacts ultimately emanating from the extraction and combustion of fossil fuels are harming the United States in myriad ways, with the impacts certain to worsen over the coming decades absent deep reductions in domestic and global GHG emissions. EPA recognized these threats in its 2009 Final Endangerment Finding under Clean Air Act Section 202(a), concluding that greenhouse gases from fossil fuel combustion endanger public health and welfare: "the body of scientific evidence compellingly supports [the] finding" that "greenhouse gases in the atmosphere may reasonably be anticipated both to endanger public health and to endanger public welfare."[87] In finding that climate change endangers public health and welfare, EPA has acknowledged the overwhelming evidence of the documented and projected effects of climate change upon the nation:

*Effects on air quality: "*The evidence concerning adverse air quality impacts provides strong and clear support for an endangerment finding. Increases in ambient ozone are expected to occur over broad areas of the country, and they are expected to increase serious adverse health effects in large population areas that are and may continue to be in nonattainment. The evaluation of the potential risks associated with increases in ozone in attainment areas also supports such a finding*."*[88]

*Effects on health from increased temperatures: "*The impact on mortality and morbidity associated with increases in average temperatures, which increase the likelihood of heat waves, also provides support for a public health endangerment finding*."*[89]

Increased chance of extreme weather events: "The evidence concerning how human induced climate change may alter extreme weather events also clearly supports a finding of endangerment, given the serious adverse impacts that can result from such events and the increase in risk, even if small, of the occurrence and intensity of events such as hurricanes and floods. Additionally, public health is expected to be adversely affected by an increase in the severity of coastal storm events due to rising sea levels."[90]

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[85] Third National Climate Assessment at 2.
[86] IPCC AR5 Synthesis Report at 46.
[87] U.S. Environmental Protection Agency, Endangerment and Cause or Contribute Findings for Greenhouse Gas Unders Section 202(a) of the Clean Air Act, 74 Fed. Reg. at 66,497 (Dec 15, 2009) ("Final Endangerment Finding").
[88] *Id.*
[89] *Id.*
[90] *Id.* at 66,497-98.

Impacts to water resources: "Water resources across large areas of the country are at serious risk from climate change, with effects on water supplies, water quality, and adverse effects from extreme events such as floods and droughts. Even areas of the country where an increase in water flow is projected could face water resource problems from the supply and water quality problems associated with temperature increases and precipitation variability, as well as the increased risk of serious adverse effects from extreme events, such as floods and drought. The severity of risks and impacts is likely to increase over time with accumulating greenhouse gas concentrations and associated temperature increases."[91]

Impacts from sea level rise: "The most serious potential adverse effects are the increased risk of storm surge and flooding in coastal areas from sea level rise and more intense storms. Observed sea level rise is already increasing the risk of storm surge and flooding in some coastal areas. The conclusion in the assessment literature that there is the potential for hurricanes to become more intense (and even some evidence that Atlantic hurricanes have already become more intense) reinforces the judgment that coastal communities are now endangered by human-induced climate change, and may face substantially greater risk in the future. Even if there is a low probability of raising the destructive power of hurricanes, this threat is enough to support a finding that coastal communities are endangered by greenhouse gas air pollution. In addition, coastal areas face other adverse impacts from sea level rise such as land loss due to inundation, erosion, wetland submergence, and habitat loss. The increased risk associated with these adverse impacts also endangers public welfare, with an increasing risk of greater adverse impacts in the future."[92]

Impacts to energy, infrastructure, and settlements: "Changes in extreme weather events threaten energy, transportation, and water resource infrastructure. Vulnerabilities of industry, infrastructure, and settlements to climate change are generally greater in high-risk locations, particularly coastal and riverine areas, and areas whose economies are closely linked with climate-sensitive resources. Climate change will likely interact with and possibly exacerbate ongoing environmental change and environmental pressures in settlements, particularly in Alaska where indigenous communities are facing major environmental and cultural impacts on their historic lifestyles."[93]

Impacts to wildlife: "Over the 21st century, changes in climate will cause some species to shift north and to higher elevations and fundamentally rearrange U.S. ecosystems. Differential capacities for range shifts and constraints from development, habitat fragmentation, invasive species, and broken ecological connections will likely alter ecosystem structure, function, and services, leading to predominantly negative consequences for biodiversity and the provision of ecosystem goods and services."[94]

In addition to these acknowledged impacts on public health and welfare more generally, climate change is causing and will continue to cause serious impacts on natural resources that the

[91] *Id.* at 66,498.
[92] *Id.*
[93] *Id.*
[94] *Id.*; *see also* Third National Climate Assessment at 195-219.

Department of Interior is specifically charged with safeguarding.[95]

Impacts to Public Lands: Climate change is causing and will continue to cause specific impacts to public lands ecosystem services. Although public lands provide a variety of difficult-to-quantify public benefits, one recent Forest Service attempt at quantification estimates the public land ecosystem services at risk from climate change at between $14.5 and $36.1 billion annually.[96] In addition to the general loss of ecosystem services, irreplaceable species and aesthetic and recreational treasures are at risk of permanent destruction. High temperatures are causing loss of glaciers in Glacier National Park; the Park's glaciers are expected to disappear entirely by 2030, with ensuing warming of stream temperatures and adverse effects to aquatic ecosystems.[97] With effects of warming more pronounced at higher latitudes, tundra ecosystems on Alaska public lands face serious declines, with potentially serious additional climate feedbacks from melting permafrost.[98] In Florida, the Everglades face severe ecosystem disruption from already-occurring saltwater incursion.[99] Sea level rise will further damage freshwater ecosystems and the endangered species that rely on them.

Impacts to Biodiversity and Ecosystems: Across the United States ecosystems and biodiversity, including those on public lands, are directly under siege from climate change—leading to the loss of iconic species and landscapes, negative effects on food chains, disrupted migrations, and the degradation of whole ecosystems.[100] Specifically, scientific evidence shows that climate change is already causing changes in distribution, phenology, physiology, genetics, species interactions, ecosystem services, demographic rates, and population viability: many animals and plants are moving poleward and upward in elevation, shifting their timing of breeding and migration, and experiencing population declines and extirpations.[101] Because climate change is occurring at an unprecedented pace with multiple synergistic impacts, climate change is predicted to result in catastrophic species losses during this century. For example, the IPCC concluded that 20% to 30% of plant and animal species will face an increased risk of extinction if global average temperature rise exceeds 1.5°C to 2.5°C relative to 1980-1999, with an increased risk of extinction for up to 70% of species worldwide if global average temperature exceeds 3.5°C relative to 1980-1999.[102]

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[95] *See* Federal Land Policy and Management Act of 1976, 43 U.S.C. §§ 1701(a)(8), 1712(c)(1); Multiple-Use Sustained Yield Act of 1960, 16 U.S.C. § 528; National Environmental Policy Act of 1969, 42 U.S.C. §§ 4331-4332.

[96] Esposito, Valerie et al., Climate Change and Ecosystem Services: The Contribution and Impacts on Federal Public Lands in the United States, USDA Forest Service Proceedings RMRS-P-64 at 155-164 (2011).

[97] U.S. Environmental Protection Agency, Climate Change and Public Lands (1999).

[98] *See* National Climate Assessment at 48; MacDougall, A. H., et al., Significant contribution to climate warming from the permafrost carbon feedback, 5 Nature Geoscience 719-721 (2012), doi:10.1038/ngeo1573.

[99] *See* National Climate Assessment at 592; Foti, Romano et al., Signs of critical transition in the Everglades wetlands in response to climate and anthropogenic changes, 110 Proceedings of the National Academy of Sciences6296-6300, (2013), doi:10.1073/pnas.1302558110.

[100] National Climate Assessment at 13.

[101] *See* Parmesan, C. and G. Yohe, A globally coherent fingerprint of climate change impacts across natural systems, 421 Nature 37–42 (2003); Root, T. et al., Fingerprints of global warming on wild animals and plants, 421 Nature 57–60 (2003); Chen, I. et al., Rapid range shifts of species associated with high levels of climate warming, 333 Science 1024–1026 (2011).

In sum, climate change, driven primarily by the combustion of fossil fuels, poses a severe and immediate threat to the health, welfare, ecosystems and economy of the United States. These impacts are felt across the nation, including upon the public lands the Secretary of the Interior is charged with safeguarding. A rapid and deep reduction of emissions generated from fossil fuels is essential if such threats are to be minimized and their impacts mitigated.

ii. The EA Ignores the Social Cost of Carbon Tool to Analyze the Cumulative Contribution of Increased Oil and Gas Development on Climate Change

As explained in the Center's comment on the PEA, although cost-benefit analysis is not necessarily the ideal or exclusive method for assessing contributions to an adverse effect as enormous, uncertain, and potentially catastrophic as climate change, BLM does have tools available to provide one approximation of external costs and has previously performed a "social cost of carbon" analysis in prior environmental reviews.[103] Its own internal memo identifies one available analytical tool: "For federal agencies the authoritative estimates of [social cost of carbon] are provided by the 2013 technical report of the Interagency Working Group on Social Cost of Carbon, which was convened by the Council of Economic Advisers and the Office of Management and Budget."[104] As explained in that report:

> The purpose of the "social cost of carbon" (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that impact cumulative global emissions. The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.[105]

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[103] *See High Country Conserv'n Advocates v. United States Forest Serv.*, 2014 U.S. Dist. Lexis 87820 (D. Colo. 2014) (invalidating environmental assessment ["EA"] for improperly omitting social cost of carbon analysis, where BLM had included it in preliminary analysis); Taylor, P., "BLM crafting guidance on social cost of carbon -- internal memo," Greenwire, E&ENews (April 15, 2015); U.S. Bureau of Land Management, Internal Memo from Assistant Director of Resources and Planning Ed Roberson titled Addressing Climate Change Under NEPA (2015). ("Roberson Internal Memo"), April 2015, *available at* http://www.eenews.net/assets/2015/04/15/document_gw_01.pdf (noting "some BLM field offices have included estimates of the [social cost of carbon] in project-level NEPA documents") (accessed May 20, 2016); *see also* Council on Environmental Quality, Revised Draft Guidance for Greenhouse Gas Emissions and Climate Change Impacts, p. 18, *available at* www.whitehouse.gov/administration/eop/ceq/initiatives/nepa/ghg-guidance (accessed Jul 29, 2015) (quantitative analysis required if GHGs > 25k tons/yr).

[104] Roberson Internal Memo.

[105] *See* Interagency Working Group on Social Cost of Carbon, United States Government, Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis - Under Executive Order 12866, May 2013, *available at* https://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf (accessed July 29, 2015); *see also* Interagency Working Group on Social Cost of Carbon, United States Government, Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, Feb. 2010, *available at* http://www.epa.gov/otaq/climate/regulations/scc-tsd.pdf (accessed July 29, 2015).

Further, other analytical tools exist to evaluate the cost of methane emissions.[106] EPA has peer reviewed and employed such a tool in its "Regulatory Impact Analysis of the Proposed Emission Standards for New and Modified Sources in the Oil and Natural Gas Sector."[107]

Leasing and development of unconventional wells could exact extraordinary financial costs to communities and future generations, setting aside the immeasurable loss of irreplaceable, natural values that can never be recovered. BLM's environmental review must provide an accounting of these potential harms and costs. The EA and BLM's response to comments fail to adequately respond to our comments on this issue.

III. Conclusion

Unconventional oil and gas development not only fuels the climate crisis but creates significant public health risks and harms to the environment. Accordingly, BLM should end all new leasing on BLM lands. Should BLM proceed with the lease sale it must thoroughly analyze the alternatives of no new leasing (or no action), and no fracking or other unconventional well stimulation methods in an EIS. Thank you for your consideration of these comments. We look forward to reviewing a legally adequate EIS for this proposed oil and gas leasing action.

Sincerely,



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[106] *See* Marten A.L., et al., Incremental CH4 and N2O mitigation benefits consistent with the US Government's SC-CO2 estimates, 15 Climate Policy (2):272-298 (2015, print publication) "Incremental CH4 and N2O mitigation benefits consistent with the US Government's SC-CO2 estimates," Climate Policy 15(2):272-298, abstract available at http://www.tandfonline.com/doi/abs/10.1080/14693062.2014.912981.

[107] *See* U.S. Environmental Protection Agency, Social Cost of Carbon, http://www3.epa.gov/climatechange/EPAactivities/economics/scc.html (accessed May 20, 2016) (noting application of social cost of methane supported by peer review); U.S. Environmental Protection Agency, Regulatory Impact Analysis of the Proposed Emission Standards for New and Modified Sources in the Oil and Natural Gas Sector, Ch. 4 (August 2015) *available at* http://www3.epa.gov/airquality/oilandgas/pdfs/og_prop_ria_081815.pdf.

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Beyond 'dangerous' climate change: emission scenarios for a new world

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The Copenhagen Accord reiterates the international community's commitment to 'hold the increase in global temperature below 2 degrees Celsius'. Yet its preferred focus on global emission peak dates and longer-term reduction targets, without recourse to cumulative emission budgets, belies seriously the scale and scope of mitigation necessary to meet such a commitment. Moreover, the pivotal importance of emissions from non-Annex 1 nations in shaping available space for Annex 1 emission pathways received, and continues to receive, little attention. Building on previous studies, this paper uses a cumulative emissions framing, broken down to Annex 1 and non-Annex 1 nations, to understand the implications of rapid emission growth in nations such as China and India, for mitigation rates elsewhere. The analysis suggests that despite high-level statements to the contrary, there is now little to no chance of maintaining the global mean surface temperature at or below 2°C. Moreover, the impacts associated with 2°C have been revised upwards, sufficiently so that 2°C now more appropriately represents the threshold between 'dangerous' and 'extremely dangerous' climate change. Ultimately, the science of climate change allied with the emission scenarios for Annex 1 and non-Annex 1 nations suggests a radically different framing of the mitigation and adaptation challenge from that accompanying many other analyses, particularly those directly informing policy.

Keywords: emission scenarios; Annex 1; non-Annex 1; cumulative emissions; climate policy; emission pathways

1. Introduction

The 2009 Copenhagen Accord [1] has received widespread criticism for not including any binding emission targets. Nevertheless, it does reiterate the international community's commitment to 'hold the increase in global temperature below 2 degrees Celsius, and take action to meet this objective

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consistent with science and on the basis of equity' [1].[1] The Accord does not, however, quantify the degree of mitigation required to meet this commitment nor does it give an indication of whether it is still possible to do so. Moreover, and despite making reference to being guided by the 'science', the Accord makes no mention of cumulative emissions as providing the scientifically credible framing of mitigation; preferring instead to focus on the 'peaking of global and national emissions as soon as possible' and the need for 'Annex I Parties to implement ... quantified economy-wide emissions targets for 2020'. While the inclusion of nearer-term targets is certainly a welcome complement to targets for 2050, the Accord still falls short of acknowledging what the science makes absolutely clear—it is cumulative emissions that matter.

This paper takes both the Accord's commitment to 'hold the increase in global temperature below 2 degrees Celsius' along with its focus on the nearer term targets, and considers these in light of post-2000 and recession-adjusted emission trends. Building particularly on previous analyses by Anderson & Bows [2] and more recently by Macintosh [3], the paper translates earlier global assessments of cumulative emissions into emission pathways for Annex 1 and non-Annex 1 nations. The importance of the distinction between Annex 1 and non-Annex 1 is also noted in the Accord. Specifically, the Accord recognizes 'that the time frame for peaking will be longer in developing countries' and also, very significantly, that 'social and economic development and poverty eradication are the first and overriding priorities of developing countries'.

2. Analysis framing

The first decade of the new millennium has witnessed unprecedented increases in emissions reflecting ongoing high levels of energy usage for heat, electricity and transport within Annex 1 nations coupled with the very rapid industrialization of many non-Annex 1 nations, in particular China and India. Total cumulative emissions produced by nations that underwent industrialization in the nineteenth century and first half of the twentieth century will be eclipsed if the five billion people currently resident in non-Annex 1 nations remain or become locked into a fossil fuel economy. Although included in non-mitigation energy scenarios (e.g. [4,5]), this dramatic potential for emissions growth within non-Annex 1 nations is typically neglected in global and national mitigation scenarios. By considering global emission budgets alongside emission pathways for non-Annex 1 nations, this paper illustrates the increasing relevance of the latter for the mitigation policies of Annex 1 nations.

Recent years have seen the development of an increasing number of global emissions scenarios, each with a differing quantity of cumulative emission over the twenty-first century and hence with different temperature implications (e.g. [2,3,6–10]). Alongside these global analyses a growing range of ever more detailed national-level energy and emission scenarios are being developed (e.g. [11–13]). Clearly, integrating national and global analyses is a prerequisite of understanding the scale and rate of mitigation, impacts and adaptation associated with differing levels of climate change. However, as it stands, such integration is rare with

[1]For the purpose of this paper, it is assumed that the '2 degrees Celsius' relates to the temperature rise above pre-industrial levels; though this is not made clear in the Accord.

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little more than perfunctory correlation between national and global emission pathways. By disaggregating selected global emission pathways into Annex 1 and non-Annex 1 nations, this paper provides an improved and more contextual understanding of the extent of the mitigation challenge specifically and the adaptation challenge more generally.[2] Such analysis cannot substitute for detailed national-level assessments, but does offer clear guidance as to the scale and rate of mitigation necessary to avoid particular rises in temperature above pre-industrial levels.[3]

The paper comprises three principal analyses. The first derives pathways for CO_2 emissions consistent with reasonable-to-low probabilities of exceeding 2°C. The second explores the implications of incorporating all greenhouse gases within the scenario pathways for a similar chance of exceeding 2°C. The third considers how a slower uptake of mitigation measures combined with later emissions peaking impact on cumulative emissions and, hence, temperature.

(*a*) *Determining the 'appropriate' probability for 2°C*

The framing of the Copenhagen Accord around the importance of 'hold[ing] to ... below 2 degrees Celsius' reflects the clear and long-established stances of both the European Union (EU) Commission and the UK Government. The EU maintains it 'must adopt the necessary domestic measures ... to *ensure* that global average temperature increases *do not* exceed preindustrial levels by more than 2°C' [15] (emphasis added). Within the UK, the language of many Government statements suggests, if not a zero probability of exceeding 2°C, at least a very low one [16]. For example, in July 2009, the UK Government published its *UK Low Carbon Transition Plan*, in which it stated explicitly that 'to avoid the most dangerous impacts of climate change, average global temperatures *must* rise no more than 2°C' [17, p. 5] (emphasis added). The previous Secretary of State for Energy and Climate Change, Ed Miliband, subsequently reiterated this commitment, stating 'we should limit climate change to a *maximum* of two degrees' [18] (emphasis added).

Although this language is qualitatively clear, the Accord, EU and the UK do not make explicit what quantitative 'risk' of exceeding 2°C is considered 'acceptable'. Without such quantification it is not possible to derive the accompanying range of twenty-first century cumulative emissions budgets from which emission pathways can be derived. In the absence of such quantification, probabilities may be inferred based on the approach developed for the Intergovernmental Panel on Climate Change's (IPCC's) reports, whereby a correlation is made between the language of likelihood and quantified probabilities [19, p. 23]. Following this approach, the Accord's, EU's and UK Government's

[2]Similar but less-contextual analyses also illustrate the division of global emissions between Annex 1 and non-Annex 1 nations (e.g. [14]).

[3]It is important to note that within non-Annex 1 nations there will be significant differences in peaking years and emission reduction rates between the rapidly industrializing nations (e.g. China) and regions such as sub-Saharan Africa. However, whilst China's total emissions are now higher than those from any other nation, their *per capita* emissions are around one fifth of those for the USA, and given current trends and agreements, are unlikely to succeed those in the USA in the next two to three decades (see note 17 for a discussion on cumulative *per capita* emissions).

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statements all clearly imply very low probabilities of exceeding 2°C, and even a highly conservative judgement would suggest the statements represent no more than a 5–33% chance of exceeding 2°C.[4]

If government responses to climate change are to be evidence-based or at least informed significantly by science, the argument for low probabilities is reinforced still further. The characterization of 2°C[5] as the appropriate threshold between acceptable and 'dangerous' climate change is premised on an earlier assessment of the scope and scale of the accompanying impacts. However, these have since been re-evaluated with the latest assessments suggesting a significant increase in the severity of some impacts for a 2°C temperature rise (e.g. [20,21]). Consequently, it is reasonable to assume, *ceteris paribus*, that 2°C now represents a threshold, not between acceptable and dangerous climate change, but between dangerous and 'extremely dangerous' climate change; in which case the importance of low probabilities of exceeding 2°C increases substantially.

Although the language of many high-level statements on climate change supports unequivocally the importance of not exceeding 2°C, the accompanying policies or absence of policies demonstrate a pivotal disjuncture between high level aspirations and the policy reality.[6] In part this reflects the continued dominance of 'end point' targets[7] rather than scientifically credible cumulative emission budgets and their accompanying emission pathways. However, even within nations such as the UK, where the relevant policy community (and recent legislation) align themselves closely with the science of climate change, the disjuncture remains.

The first report of the UK's Committee for Climate Change (CCC) [8] heralded a significant departure from a focus on end-point and typically long-term targets. Complementing the UK's 2050 emission-reduction target with short-term budgets, the report proceeds to describe an emissions pathway out to 2050, acknowledging explicitly the need to re-align policy with cumulative emissions rather than simplistic targets. Nevertheless, although the UK Government's framing of its climate change legislation is the first to detail emission pathways, it is still far removed from its and others' high-level commitments to 'limit climate change to a *maximum* of two degrees' [18]. As it stands the carbon budget and emission pathway now enshrined in legislation are underpinned by analysis assuming a 63 per cent probability of exceeding 2°C [8, p. 21];[8] a position that cannot be reconciled with the probabilities implied repeatedly by Government statements (i.e. at their highest 5–33% of exceeding 2°C).

[4]At the 'less likely' end of the spectrum, the IPCC categorizes a 33 per cent probability of missing or exceeding something as 'unlikely', 10 per cent as 'very unlikely', 5 per cent as 'extremely unlikely' and 1 per cent as 'exceptionally unlikely'.

[5]Or at least the rate of increase associated with a 2°C rise by 2100.

[6]Although this paper explicitly steers away from issues of governance, there are clearly major implications for all tiers of government, and wider public and private decision making in both bringing about the scale of mitigation accompanying 2°C and responding to the impacts and associated adaptation of a failure to significantly mitigate.

[7]Typically 2050 but also, more recently, 2020.

[8]The 63 per cent probability of exceeding 2°C is an outcome of the CCC's modelling approach and relates to its global cumulative emissions budget. Given the UK budget is premised on the CCC's choice of regime for apportioning global emissions between nations, it is reasonable to describe the UK's budget as correlating with a 63 per cent chance of exceeding 2°C, albeit with the important caveat that other nations, at least collectively, do not exceed their apportioned emissions budgets.

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While the climate specialists within the CCC are aware of the implications of their analysis and conclude explicitly that 'it is not now possible to ensure with high likelihood that a temperature rise of more than 2°C is avoided' [8, p. 16], the language of many policy statements suggests such implications are not either understood or accepted. In general there remains a common view that underperformance in relation to emissions now can be compensated with increased emission reductions in the future.[9] Although for some environmental concerns delaying action may be a legitimate policy response, in relation to climate change it suggests the scale of current emissions and their relationship to the cumulative nature of the issue is not adequately understood.

From a mitigation perspective, the gap between the scientific and policy understanding of the challenge needs urgently to be addressed. What is perhaps less evident is the implication of this gap for adaptation. As it stands and in keeping with the dominant policy discourse, the framing of much of the detailed research and practice around adaptation, if guided quantitatively at all, is informed primarily by the 2°C characterization of dangerous climate change. Yet, as the impacts of rising temperatures are unlikely to be linear and also given rising temperatures are increasingly likely to be accompanied by additional feedbacks and hence further temperature rises, adaptation must consider more extreme climate change futures than those associated with 2°C [22]. This is certainly important for the transition of Annex 1's existing built environment and infrastructures. However, it is appreciably more important for the development of new built environments, infrastructures, agricultural practices and water regimes etc. within the non-Annex 1 nations, where an opportunity still exists for societies to locate in areas geographically less vulnerable to the impacts of climate change.[10]

3. Scenario pathway assumptions

Scenario approaches are increasingly used within mitigation and adaptation research for visioning alternative futures, exploring consistency, assessing plausibility and providing policy guidance [23]. These approaches vary in terms of 'backcasting' and 'forecasting', and range from top-down and quantitative through to more bottom-up and qualitative assessments. The scenario pathways developed in this paper are explicitly 'backcasting' and quantitative. They are not vision-based, but rather are premised on a cumulative emissions framing of climate change for which richer and more qualitative scenarios could be developed in terms of mitigation, impacts and adaptation. With regard to exploring the consistency of scenarios, the relative simplicity of the analysis presented here permits the connection between temperature targets and emission reductions to be readily assessed. In that sense, the scenarios are internally consistent. This

[9]This is particularly evident in the continued recourse to the implementation of future and innovative low-carbon technologies (e.g. carbon capture and storage, nuclear power, marine-based biofuels, etc.) as the principal route by which emissions reductions will be achieved; a position that cannot be reconciled with the rate of reductions implied in high-level statements on 2°C.

[10]Such geographical vulnerability will need to be considered alongside other cultural, institutional and economic factors if resilience to the impacts of climate change is to be embedded in development.

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contrasts with most, if not all, bottom-up mitigation analyses where consistency is constrained to issues of mitigation with climate related impacts typically exogenous to the analyses.[11]

(*a*) *Cumulative emission budget*

The scenario pathways developed in this paper illustrate quantitatively the scale of mitigation implied in high-level policy statements on 2°C. Moreover, and with direct reference to Annex 1 and non-Annex 1 nations, the scenario pathways demonstrate the disjuncture between such high-level statements and the emission pathways proposed by many policy-advisers and academics. The scenario pathways are all premised on a cumulative emission budget approach, building particularly on the work of Macintosh [3] and Anderson & Bows [2,24] but also on a range of wider studies [7,25,26].

While Macintosh [3] focused on CO_2-only emissions in correlating twenty-first century budgets with global mean temperatures (denoted by the CO_2 plus regime), the budgets within Anderson & Bows' analysis were for the basket of six Kyoto gases. Given there are merits and drawbacks for each of the budgetary regimes, both are considered in this paper.

(i) *The CO_2-plus regime ($C+$) and twenty-first century budgets*

The budgetary regime used by Macintosh [3] separates CO_2 emissions from non-CO_2 greenhouse gases and aerosols by applying Meinshausen *et al.*'s [7] assumptions on the net radiative forcing of the non-CO_2 components. Consequently, for a given temperature and assuming other factors remain unchanged, the cumulative budget for CO_2-only is lower than would be the equivalent CO_2e greenhouse gas value. The advantage of this regime is that non-CO_2 emissions, including aerosols, are more robustly incorporated than is possible through the coarser regimes reliant on global warming potential. However, although offering significant scientific merit, the approach poorly represents the contextual framing of emission scenarios, for example, the link between aerosol emissions and assumptions about fossil fuel combustion and rates of deforestation.

The CO_2-only budgets considered in this paper are the same as the middle and lower estimates used by Macintosh [3]. Macintosh also analysed a higher budget of 2055 $GtCO_2$ (560 GtC) as an 'outer marker' of abatement necessary for avoiding a 2°C. However, given the analysis here illustrates pathways offering an 'unlikely to extremely unlikely'[4] chance of exceeding 2°C, Macintosh's high budget is excluded from the analysis.

[11]For example, few if any energy scenarios addressing mitigation include reductions in efficiency of thermal power stations if the temperature of cooling water rises, the potential of culturally distinct migrants to embed alternative practices into established transport and housing energy use, how drought conditions may impact energy use for desalination and grey-water recycling or the impacts of changing precipitation and temperature on biomass yields. This is not a criticism of existing bottom-up analyses, but a recognition that the range of impacts associated with different levels of climate change and differential impacts on temperature and precipitation make bottom-up analysis much more challenging, if not impossible, with regard to achieving consistency.

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The two remaining budgets, 1578 $GtCO_2$ (430 GtC) and 1321 $GtCO_2$ (360 GtC), are taken directly from Macintosh [3]. The first is informed by the Garnaut Climate Change Review's 450 ppm CO_2e stabilization scenario [27][12] and according to Macintosh [3] provides an approximate 50 per cent chance of not exceeding 2°C. The latter, according to Macintosh reflects the 'risk that climate-carbon cycle feedbacks respond earlier and more strongly than previously believed' and corresponds with a higher probability of not exceeding 2°C.[13]

(ii) *The basket of six regime (B6) and twenty-first century budgets*

The B6 regime, used previously by Anderson & Bows [2], assumes the correlation between global mean temperature and cumulative emissions of the basket of six Kyoto gases as adequate for informing policy-makers of the scale of mitigation necessary. In relation to aerosols it assumes they are both short-lived and sufficiently highly correlated with fossil fuel combustion and deforestation as to have little net impact on temperatures associated with twenty-first century low-emission scenario pathways [10].[14] Moreover, it assumes the 'CO_2 equivalence' of Kyoto gases reasonably captures the warming implications of non-CO_2 emissions from producing food for an increasing and more affluent population. Evidently, the CO_2e regime is not as scientifically robust as the CO_2-only regime, but it more appropriately captures the contextual implications of alternative emission scenario pathways.

The two CO_2e budgets within this paper are those used within Anderson & Bows [2] and represent the low (1376 $GtCO_2$e) and high (2202 $GtCO_2$e) ends of the IPCC AR4 cumulative emission range for stabilization at 450 ppmv CO_2e [29]. Currently Meinshausen's *et al.*'s PRIMAP tool [28] does not permit a direct calculation of the probability of exceeding 2°C for emission pathways that maintain a substantial and long-term emission burden. However, a coarse-level but nevertheless adequate estimate is possible if the long lived gases within the 'emissions floor'[15] are added to the 2000–2050 cumulative values.

(*b*) *Empirical data*

The continued and high level of current emissions is consuming the twenty-first century emission budget at a rapid rate. Consequently, it is necessary to use up-to-date and complete emissions data to construct future emission pathways. Within this paper data are aggregated for the latest year available from a number of different sources.

[12]For more details see Macintosh [3].

[13]Probabilities based on Meinshausen *et al.*'s [7] model assumptions can be calculated using the PRIMAP tool [28] if the 2000–2049 emissions are known.

[14]'Twenty-first century low-emission' scenarios are premised on low fossil fuel combustion and low deforestation rates. The probabilities related to 2°C in the B6 regime do however take into account the radiative forcing of the different emissions including aerosols based on assumptions embedded in Meinshausen's *et al.*'s PRIMAP tool for estimating probabilities of exceeding 2°C [28].

[15]Refers to the lowest level of annual emissions considered viable in the scenario. These emissions are typically related to agriculture and food production.

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(i) *Energy and industrial process emissions*

For energy and process related CO_2 emissions from 2000 until 2008, data are taken for each Annex 1 and non-Annex 1 nation from the Global Carbon Project using the Carbon Dioxide Information Analysis Centre (CDIAC) [30] and aggregated to produce an Annex 1 and non-Annex 1 total. The nationally constructed data from this source exclude CO_2 emissions from international aviation and shipping. To include these additional emissions, data are not taken from CDIAC as their bunker fuel CO_2 emission data are not disaggregated between nations and global marine bunker emissions are based on sales records that currently underestimate significantly the global greenhouse gas emission burden [31]. Instead, international aviation CO_2 for Annex 1 nations is taken from the memo submissions to the United Nations Framework Convention on Climate Change (UNFCCC) [32]. Non-Annex 1 international aviation CO_2 data are taken from the International Energy Agency [33] as non-Annex 1 nations do not submit this information to the UNFCCC. For international marine bunkers, the data have previously been subject to high levels of uncertainty [34–36]. However, a recent study by the International Maritime Organisation [37] has produced a time series for greenhouse gas emissions associated with international shipping activity. These data provide a figure for the global aggregated CO_2 and other greenhouse gas emissions between 1990 and 2007. However, the data are not disaggregated into national statistics. To estimate the proportion of international shipping CO_2 emissions split between Annex 1 and non-Annex 1 nations, an assumption is taken that shipping activity is directly proportional to each nation's proportion of global GDP. This crude method of apportionment was used previously (e.g. [36]), and given difficulties in apportioning international shipping emissions to nations [38,39], is also used here as an adequate, though inevitably coarse-level, division of emissions between Annex 1 and non-Annex 1 nations.[16]

(ii) *Deforestation and land-use change*

For deforestation and land-use change (hereafter referred to as 'deforestation') data between 2000 and 2008 carbon emissions are again taken from the Global Carbon Project Carbon Budget Update 2009 [41]. Their figures are estimated based on deforestation statistics published by the United Nations Food and Agriculture Organization [42] and a bookkeeping method up until 2005. The 2006–2008 emissions are derived from estimates of fire emissions using satellite data from the Oak Ridge National Laboratory Distributed Active Archive Center Global Fire Emissions Database in combination with a biogeochemical model [43].

(iii) *Non-CO_2 greenhouse gas data*

The non-CO_2 greenhouse gas emission data for 2000–2005 are based on the US Environmental Protection Agency (EPA) estimates [44]. For 2006 and 2007, data are taken from an interpolation between the 2005 and 2010 EPA projections.

[16]A hybrid approach for apportioning aviation emissions between regions may provide insights into potential apportionment regimes for shipping [40].

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This dataset is identical to the one used within Anderson & Bows [2] but in this case individual national statistics are aggregated to produce the Annex 1 and non-Annex 1 totals.

(*c*) *Economic downturn*

The economic downturn of 2007–2009 had a direct impact on greenhouse gas emission growth rates, particularly those associated with energy. Although the crisis is beginning to show within 2008 emissions inventories, data were not available for either 2008–2010 bunker fuel emissions or 2009–2010 domestic fossil fuel CO_2 emissions. In the absence of such data, estimates draw on the work of Macintosh [3] and the Global Carbon Project [41]. For Annex 1 nations, fossil fuel CO_2 (excluding bunkers) is assumed to decline by 6 per cent in 2009, stabilizing at 0 per cent in 2010. Non-Annex 1 nations are assumed to exhibit 0.5 per cent decline in emissions in 2009, but given China is already reporting high levels of growth for early 2010, the 2010 growth figure is assumed to be half the recent decade's average (i.e. 2.7%). Consequently, growth in global fossil fuel CO_2 (excluding bunkers) is assumed to be −3.0 per cent in 2009 rising to 1.5 per cent in 2010. For international aviation bunkers, it is estimated Annex 1 nations' emissions declined by 2 per cent in 2008, remaining static in 2009 and 2010. Non-Annex 1 nation aviation bunkers are assumed to be stable at 2007 levels until 2009, after which they grow at 2 per cent in 2010, again half the recent decade's average. Given the international marine bunker figures are based on proportions of global GDP, the same percentage growth rates for national emission trends are applied as for Annex 1 and non-Annex 1 domestic CO_2 emissions between 2008 and 2010.

For the emissions of non-CO_2 greenhouse gases, it is assumed that their growth is also impacted by the economic downturn. However, non-CO_2 greenhouse gas emission growth rates are typically lower than those for global fossil fuel CO_2 by approximately 1–2% per year. Given the absence of recent data from the EPA, Annex 1 and non-Annex 1 non-CO_2 greenhouse gas emissions are assumed to proportionally follow the percentage change in their CO_2 counterparts. In other words, if the rate of growth halves for Annex 1 CO_2 emissions, then the rate of growth for non-CO_2 greenhouse gas emissions is also assumed to halve.

4. Scenario pathway development

Following a brief explanation of how historical and deforestation emissions are accounted for, the construction of the scenario pathways involves the following steps.

— Decide on a global cumulative CO_2 and greenhouse gas emission budget associated with a range of probabilities of exceeding 2°C.
— Construct emission pathways for the *non-Annex 1* nations with varying peak dates.
— Construct emission pathways for the *Annex 1* nations for which the cumulative emissions, when added to non-Annex 1 and deforestation emissions, do not exceed the global '2°C' cumulative budget.

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— Construct emission pathways for the non-Annex 1 nations with a 2030 peak date and more 'orthodox' annual reduction rates following the peak.
— Construct emission pathways for the Annex 1 nations with a 2015 peak date and 'orthodox' annual emission-reduction rates following the peak.
— Assess the potential future climate impact of these more 'politically acceptable' and 'economic feasible' pathways.

(*a*) *Historical emissions*

In developing emission pathways for Annex 1 and non-Annex 1 regions it is necessary to make explicit which region is deemed responsible for which emissions. While the following analysis focuses specifically on the period 2000–2100, it is important to reflect briefly on the treatment of recent historical emissions. Given temperature correlates with cumulative emissions of greenhouse gases, a case could be made for considering the responsibility for twentieth century emissions in apportioning future twenty-first century emission-space between Annex 1 and non-Annex 1 regions. However, the highly constrained emission-space now remaining for a 2–3°C rise in global mean surface temperature leaves little option but to explicitly neglect the responsibility of historical emissions in developing pragmatic twenty-first century emission profiles.[17] Getting an appropriate balance of responsibilities is a matter of judgement that inevitably will not satisfy all stakeholders and certainly will be open to challenge. As it stands, the approach adopted for this paper in which historical (and deforestation) emissions are taken to be global overheads,[18] is a pragmatic decision that, if anything, errs in favour of the Annex 1 nations.[19]

(*b*) *Deforestation emissions*

To explore the constraints on emissions from Annex 1 nations of continued growth in emissions from non-Annex 1 nations, only data for fossil fuel combustion, industrial processes and agriculture are split between Annex 1 and non-Annex 1. Deforestation emissions are treated as a global overhead and thus removed from the available emission budgets prior to developing the pathways. Such an approach could be argued to unreasonably favour non-Annex 1 nations as deforestation emissions occur within their geographical boundaries. However, given most Annex 1 countries have already deforested (emitting CO_2) it could

[17]Factoring *twentieth* century emissions from Annex 1 nations into calculations of the 'fair' emission space available for Annex 1 in the *twenty-first* century would leave Annex 1 nations already in 'emission debt'. Whilst such an outcome may have some moral legitimacy, it evidently would not provide for a politically consensual framing of emission apportionment. However, the implications of including twentieth century emissions and the concept of emission debt may guide the scope and scale of climate-related financial transfers (arguably as reparation) between Annex 1 and non-Annex 1 nations.

[18]Emissions not attributable to any specific geographical location.

[19]It is worth noting that a recent paper [45] based on analysis undertaken at Tsinghua University in Beijing makes the case that 'reasonable rights and interests should be strived for, based on the equity principle, reflected through cumulative emissions *per capita*'. Building on this *cumulative emissions per capita* approach, the authors demonstrate how China's historical cumulative emissions are only one-tenth of the average in industrial countries and one-twentieth that of the USA.

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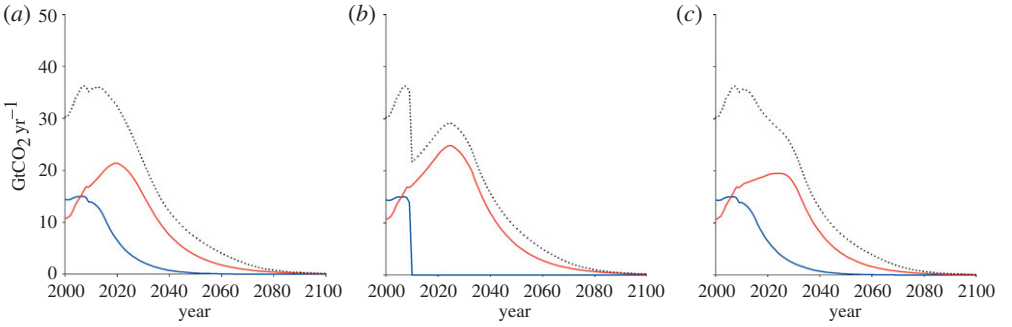


Figure 1. CO_2 scenarios for approximately 37% chance of not exceeding 2°C. All scenario pathways ((*a*) C+1, (*b*) C+2, (*c*) C+3) are for the same cumulative twenty-first century CO_2 budget of 1321 $GtCO_2$ (blue line, Annex 1; red line, non-Annex 1; dotted line, global including deforestation).

also be considered unreasonable to ascribe all of the non-Annex 1 deforestation emissions solely to non-Annex 1 nations. The global overhead approach applied here does not absolve non-Annex 1 nations of responsibility for deforestation emissions, as their available budget for energy-related emissions, along with the budget for Annex 1 nations' energy emissions, will be reduced as a consequence of the emissions from deforestation. The deforestation scenario used throughout the paper is taken as an average of the two scenarios used within Anderson & Bows [2], but updated to include the most recent emission estimates provided by the Global Carbon Project [41]. The original Anderson and Bows scenarios were optimistic compared with scenarios within the literature; the updated estimate used for this paper (266 $GtCO_2$ over the twenty-first century) continues in this optimistic vein.

(*c*) *CO_2 plus* (*C+*)

All C+ scenario pathways take the development of emissions within the non-Annex 1 nations as the starting point and then build a related Annex 1 emission pathway that holds CO_2 emissions within the chosen budget. While non-CO_2 greenhouse gases are not included in the C+ scenario pathway, CO_2 emissions associated with international bunkers and deforestation are included. The first three scenario pathways (C+ pathways 1–3 shown in figure 1) use the lowest CO_2 budget from Macintosh [3]. The second three (C+ pathways 4–6 in figure 2) use the mid-level CO_2 budget from the same paper.

C+1 assumes non-Annex 1 emission growth continues at lower than economic downturn rates from 2010 to 2015 (3% per year) and that emissions peak in 2020. For global emissions to remain within the budget, Annex 1 nations are assumed to reduce their emissions from 2011 onwards towards virtually complete decarbonization by 2050. Despite such significant reductions in Annex 1 nations (approx. 11% per year), non-Annex 1 nations' emissions still need to decline at 6 per cent per year following their peak in 2020 if global emissions are to remain within the cumulative budget. This scenario pathway results in a 56 per cent reduction from 1990 levels in emissions for Annex 1 nations by 2020, 98 per cent by 2050. Non-Annex 1 nations increase their emissions to 71 per cent higher than

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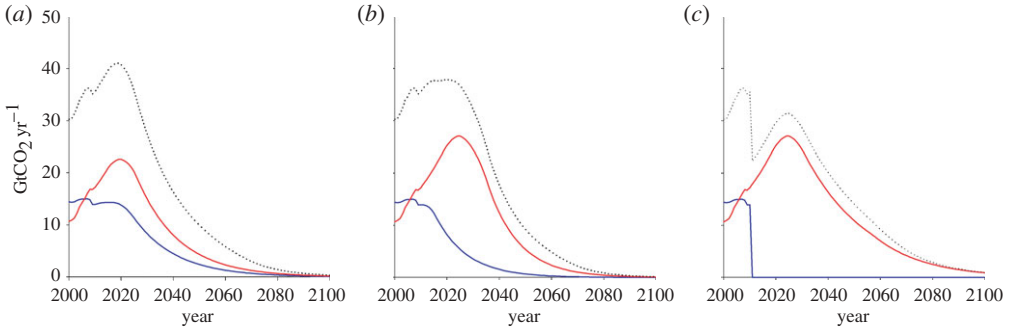


Figure 2. CO_2 scenarios for approximately 50% chance of not exceeding 2°C. All scenario pathways ((*a*) C+4, (*b*) C+5, (*c*) C+6) are for the same cumulative twenty-first century CO_2 budget of 1578 $GtCO_2$ (blue line, Annex 1; red line, non-Annex 1; dotted line, global including deforestation).

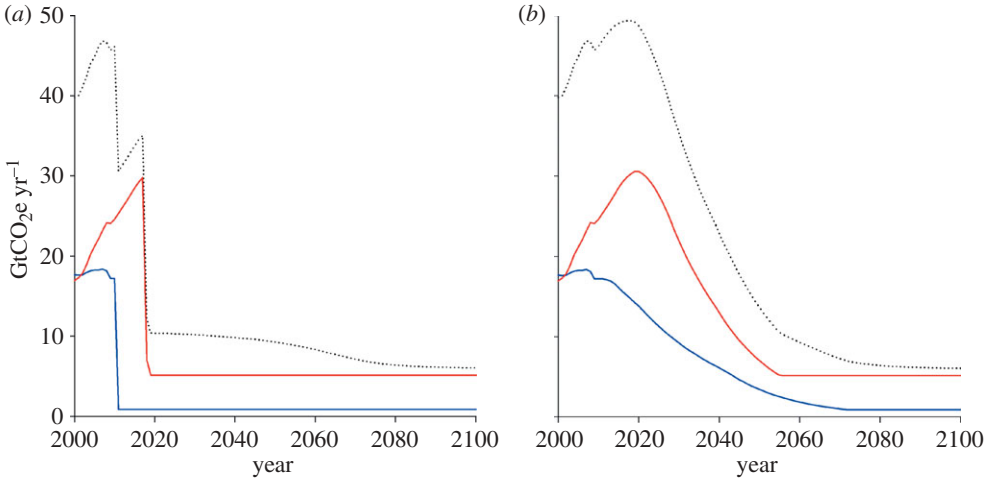


Figure 3. Kyoto gas scenarios for approximately 39–48% chance of not exceeding 2°C ((*a*) B6 1 not viable). For (*b*) B6 2, the cumulative twenty-first century CO_2e budget is 2202 $GtCO_2e$ (blue line, Annex 1; red line, non-Annex 1; dotted line, total including deforestation).

1990 levels by 2020 and then reduce them to 76 per cent below 1990 levels by 2050. Using the PRIMAP tool developed by Meinshausen *et al.* [7,28] this scenario pathway is estimated to have a 36 per cent[20] probability of exceeding 2°C.

Following the same approach, C+2 has non-Annex 1 emissions continuing to grow at a lower than pre-economic downturn rate until 2020 (3% per year), and peak in 2025. However, if this is the case, non-Annex 1 nations use the entire carbon budget and leave no emission budget for Annex 1 nations. Thus, this scenario pathway is not compatible with the lower of the cumulative carbon budgets.[21]

[20]PRIMAP provides a range of probabilities and a 'best estimate' using cumulative emissions between 2000 and 2049. Here, 'best estimates' are presented; probabilities may vary slightly for the same twenty-first century budget, owing to differences in the 2000–2049 emissions.
[21]Given it is not possible to have an immediate cessation of emissions from all Annex 1 nations.

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To explore the potential of providing for more acceptable reduction rates while still offering a 'reasonable' chance of not exceeding 2°C, C+3 assumes non-Annex 1 nations' emissions grow at a much reduced rate (1% per year) until 2025. Given this, and if Annex 1 emissions begin to reduce immediately (as in C+1), non-Annex 1 nations' emissions must still reduce at 7–8% per year after the peak date in order for global emissions to remain within the cumulative budget. Following the dip in emissions owing to the economic downturn, and as a result of a step-change in emission growth from non-Annex 1 nations, global emissions peak in 2011 and Annex 1 nations' future emissions do not grow any higher than current levels. This plausible but highly unlikely scenario has a 37 per cent chance of exceeding 2°C according to PRIMAP [28].

The next three scenario pathways (figure 2) use the higher budget of 1578 $GtCO_2$ within Macintosh [3]. C+4 assumes non-Annex 1 nation emissions grow at 4 per cent per year until 2015 peaking in 2020. The Annex 1 nations have more room to grow in early years than in C+1, but are assumed to reach a peak by 2015. Global emissions thus peak in 2019 with Annex 1 emissions 6 per cent below 1990 by 2020 and 84 per cent by 2050. Non-Annex 1 emissions are 186 per cent above 1990 levels in 2020 and 45 per cent below them by 2050. Global emissions are 67 per cent below 1990 by 2050. Both Annex 1 and non-Annex 1 emissions are assumed to decline post-peak at 5–6% per year. This scenario pathway has an estimated 50 per cent chance of exceeding 2°C according to PRIMAP [28].

C+5 again uses the higher budget within Macintosh [3] but assumes non-Annex 1 emissions to continue to grow at 4 per cent per year rates until 2020, and peak in 2025 with a rapid decline to a maximum of 7–8% per year. To remain within budget, Annex 1's emissions peak by 2010 and decline at 7–8% per year. Within this scenario pathway, global emissions are broadly flat between 2014 and 2022, although emissions are highest in 2020. Thus the penalty for a five year delay in the non-Annex 1 peak date is an additional 2 per cent per year on top of the emission reduction rate for both Annex 1 and non-Annex nations, in addition to an immediate Annex 1 reduction. C+5 has a 52 per cent chance of exceeding 2°C. C+6 uses the same higher budget but illustrates that if reductions are lower, at 4–5% per year for non-Annex 1 nations following the peak date, no emission space is available for Annex 1 nations.

(*d*) *Basket of six scenario pathways* (*B6*)

In a similar approach to the C+ pathways, all B6 pathways (figures 3 and 4) take the development of emissions within the non-Annex 1 nations as the starting point and then build a related Annex 1 emission scenario pathway that must, in this case, keep total greenhouse gas emissions within the chosen budget. The significant difference between the B6 and the C+ pathways is that the given emission budget is assumed to apply to the full basket of 6 greenhouse gases mirroring the approach taken in Anderson & Bows [2]. In addition to considering the effect of non-CO_2 greenhouse gases contributing to the overall budget, an essential difference is the requirement for significant emissions space post-2050 to allow for greenhouse gas emissions (specifically N_2O and CH_4) associated with food production for an approximate 9.2 billion global population (based on UN

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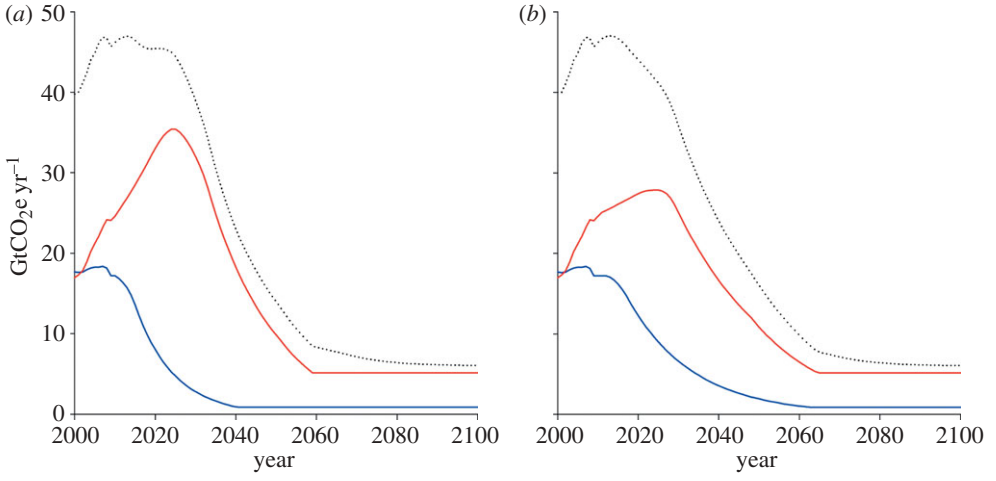


Figure 4. Kyoto gas scenarios for approximately 38–48% chance of not exceeding 2°C ((*a*) B6 3, (*b*) B6 4). The cumulative twenty-first century CO_2e budget is 2202 $GtCO_2e$. Blue line, Annex 1; red line, non-Annex 1; dotted line, total including deforestation.

median estimate for 2050 [46]). In an update to the previous Anderson & Bows [2] study, the assumed minimum level of greenhouse gas production related to food is more optimistic still at 6 $GtCO_2e$ per year as opposed to 7.5 $GtCO_2e$ per year. This is in line with the value chosen by the UK [8] and results in an estimated 0.67 tCO_2e per person from 2050 onwards for food-related non-CO_2 greenhouse gases compared with an approximate figure of 0.95 $GtCO_2e$ per person for 2010 [44,46]. Assuming by 2050 there are 7.9 billion people in non-Annex 1 nations, and 1.3 billion in Annex 1 nations [46], and assuming food consumption is more evenly balanced between Annex 1 and non-Annex 1 nations than currently, this would allow approximately 5.1 $GtCO_2e$ as a minimum annual greenhouse gas emission for non-Annex 1 nations and 0.86 $GtCO_2e$ per year for Annex 1 nations.

B6 1 uses the IPCC 'low' emission budget and assumes that between 2010 and 2015 non-Annex 1 emissions grow at slightly lower (3% per year) than pre-economic downturn rates and peak by 2020 (figure 3). Given the food-related non-CO_2 greenhouse gases post-2050, emissions from 2017 onwards for non-Annex 1 nations must tend immediately towards the emissions floor of 5.1 $GtCO_2e$. In other words, this scenario pathway is not viable.

B6 2 makes identical assumptions to B6 1 but for the 'high' IPCC emission budget (figure 3). The additional space allowed leads to a viable scenario pathway, where non-Annex 1 emissions peak in 2020, while Annex 1 nation emissions decline from 2010 onwards. Emission reductions for non-Annex 1 nations in this case are 6 per cent per year, while for Annex 1 they gradually build from around 3 per cent per year for 2015 to 2020 to 6 per cent later in the century. The PRIMAP tool to estimate the probability of exceeding the 2°C threshold assumes the vast majority of emissions are released pre-2050 (fig. 2 in [7]). Given that within the B6 scenario pathways there is a substantial cumulative emission total for the post-2050 emissions (with at least 300 $GtCO_2e$ from greenhouse gases associated with

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food production), inputting the 2000–2049 cumulative total for each B6 scenario into PRIMAP will result in an underestimate of the probability of exceeding 2°C. To account for this underestimate, an alternative probability is calculated assuming the following.

— The shorter-lived nature of methane compared with N_2O results in a negligible impact on post-2050 warming from methane.[22]
— N_2O and methane each account for approximately 50 per cent of the non-CO_2 greenhouse gases post-2050 (Smith, personal communication).
— The amount of non-CO_2 greenhouse gas emissions released per year possible post-2050 is 6 $GtCO_2e$ (in line with assumptions made by the UK CCC [8]) of which 3 $GtCO_2e$ per year is from N_2O.
— Thus 150 $GtCO_2e$ of cumulative emissions are added to the pre-2050 emissions to estimate an alternative probability.

If 150 $GtCO_2e$ is added to the cumulative emission total for each scenario, PRIMAP estimates an approximate ten percentage point increase in probability of exceeding 2°C (see table 1, figure is in brackets). For example, B6 2 has at least a 39 per cent chance of exceeding 2°C and is potentially as high as 48 per cent.

Both B6 3 and B6 4 take the IPCC's 'high' cumulative budget as a constraint. B6 3 assumes non-Annex 1 nation emissions peak in 2025 following a growth of 3 per cent per year between 2010 and 2020 (figure 4). With steep emission reductions for non-Annex 1 nations post-peak of 6 per cent per year, Annex 1 nations would need to reduce emissions from 2010 onwards at more than 10 per cent per year to remain within the high IPCC cumulative budget. More gradual reductions in emissions from non-Annex 1 nations would render this scenario pathway impossible. B6 3 has the same probability of exceeding 2°C as B6 2.

B6 4 mirrors the assumptions within C+3, with considerably slower growth of 1 per cent per year until a peak date in 2025 (figure 4). The emission reductions post-peak for non-Annex 1 nations are 4–5% per year, whereas for Annex 1 nations, following a levelling off of emissions until 2014, emissions decrease at 6 per cent per year. This scenario pathway has at least a 38 per cent probability of exceeding 2°C, and potentially as high as 47 per cent once post-2050 emissions are factored in.

(*e*) *Orthodox scenario pathways*

The final scenario pathways developed are unconstrained by a particular emission budget (figure 5). For both the C+ and B6 regimes, pathways are constructed that assume non-Annex 1 nations' emissions continue to develop along their current trajectory until 2025, peaking in 2030, then reducing at

[22]This is an explicitly conservative assumption and results in slightly higher probabilities of not exceeding 2°C than would be the case if some allowance were to be made for post-2050 emissions of methane.

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Table 1. Summary of scenario pathway characteristics.

scenario pathway	global 21st century CO_2 or greenhouse gas budget in $GtCO_2$ or [$GtCO_2e$]	Annex 1 peak date/21st century cumulative emissions in $GtCO_2$ or [$GtCO_2e$]	non-Annex 1 peak date/21st century cumulative emissions in $GtCO_2$ or [$GtCO_2e$]	global peak date	Annex 1 % reduction on 1990 levels by 2020 (2050)	non-Annex 1 % reduction on 1990 levels by 2020 (2050)	post-peak Annex 1 rate of reduction	post-peak non-Annex 1 rate of reduction	post-peak global rate of reduction (includes deforestation)	approximate % of exceeding 2°C (based on 2000–2049 emissions using PRIMAP)
C+1	1321	2007 313	2020 742	2012	56% (98%)	+1714% (54%)	10–11%	6–7%	6–7%	36%
C+2[a]	1321	2007 139	2025 916	2007	100% (100%)	+193% (27%)	—	6–7%	6–7%	
C+3	1321	2007 313	2025 742	2007	56% (98%)	+143% (54%)	10–11%	7–8%	7–8%	37%
C+4	1578	2007 532	2020 780	2019	6% (84%)	+186% (45%)	5–6%[b]	5–6%	5–6%	50%
C+5	1578	2007 363	2025 949	2020	44% (95%)	+220% (32%)	8%	7–8%	7–8%	52%
C+6[a]	1578	2007 153	2025 1159	2024	100% (100%)	+220% (+38%)	—	4–5%	4–5%	—
B6 1[a,c]	[1376]	2007 [265]	2017 [841]	2017	95% (95%)	61% (61%)	—	—	—	—
B6[c] 2	[2202]	2010 [639]	2020 [1293]	2017	25% (82%)	+135% (46%)	4–6%	5–6%	3%	39% (48%)[d]
B6[c] 3	[2202]	2007 [429]	2025 [1503]	2013–2018	57% (95%)	+154% (24%)	8–10%	6–7%	4–5%	39% (48%)[d]
B6[c] 4	[2202]	2007 [552]	2025 [1380]	2013	34% (90%)	+111% (17%)	6%	4–5%	4–5%	38% (47%)[d]
orthodox C+	2741	2015 [729]	2030 1747	2027	2% (60%)	+223% (+163%)	3%	3%	3%	88%
orthodox B6	[3662]	2015 [891]	2030 [2501]	2028	5% (62%)	+180% (128%)	3%	3%	3%	88% (92%)[d]

[a]These scenario pathways are not viable as they could not remain within the carbon budget prescribed.

[b]This is the reduction rate following the period of relatively stable emissions until 2016.

[c]All B6 scenario pathways assume an 'emission floor' of $6GtCO_2e$ for food-related emissions for an approximate 9 billion population post-2050 until 2100. If a different 'emission floor' were to be used, emission reduction rates would be altered for the same cumulative values.

[d]The figure in brackets illustrates a higher probability to take into account the ongoing emissions associated with food production as opposed to greenhouse gas emissions tending to zero.

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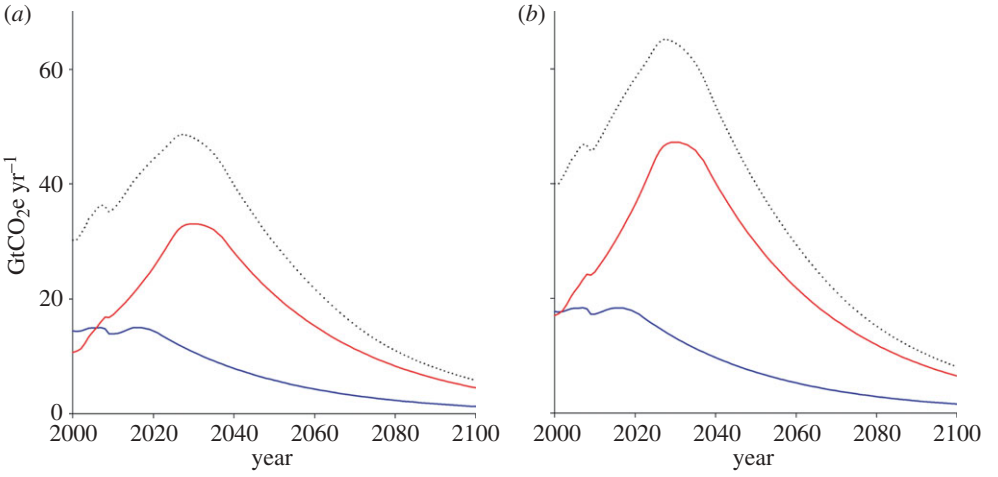


Figure 5. Emission scenarios for approximately 88–92% chance of not exceeding 2°C. Both plots illustrate 'orthodox' mitigation pathways with (*a*) C+ for CO_2 only (twenty-first century cumulative emissions: 2741 $GtCO_2$) and (*b*) B6 for Kyoto gases (twenty-first century cumulative emissions: 3662 $GtCO_2e$). Blue line, Annex 1; red line, non-Annex 1; dotted line, total including deforestation.

a rate considered politically and economically acceptable[23] (3% reduction per year). For the Annex 1 nations, emissions are assumed to be relatively stable with a peak in 2016 and subsequent emission reductions of 3 per cent per year. These scenario pathways both result in an 88 per cent chance of exceeding the 2°C threshold (potentially 92% for orthodox B6). Furthermore, their twenty-first century cumulative budgets suggest the future temperature increase compared with pre-industrial times is more likely to be of the order of 4°C rather than 2°C.

For orthodox C+, cumulative emissions of CO_2 alone are 2,741 $GtCO_2$. Cumulative emissions of approximately 2700 $GtCO_2$ are associated with stabilization of 550 ppmv CO_2. Figures in excess of 3500 $GtCO_2e$ can be assumed to be closer to the 750 ppmv range. Orthodox B6 has cumulative emissions of greenhouse gases of 3662 $GtCO_2e$, thus a reasonable probability of exceeding 4°C.

5. Discussion

(*a*) *CO_2 plus (C+)*

Although six C+ pathways were developed in the previous section, two were rejected for exceeding the constraints on cumulative CO_2 budgets related to the 2°C temperature threshold. One exceeded the lower of the two chosen

[23]The pathway of the CCC's [8] most challenging scenario, '2016:4% low', has post-peak emissions reducing at 3.5 per cent per year from all sources. Stern [6] states 'there is likely to be a maximum practical rate at which global emissions can be reduced' pointing to 'examples of sustained emissions cuts of up to 1 per cent per year associated with structural change in energy systems' and that 'cuts in emissions greater than this (1%) have historically been associated only with economic recession or upheaval'. Stern concludes 'it is likely to be difficult to reduce emissions faster than around 3 per cent per year' [6, pp. 201–204]. The most stringent of the ADAM scenarios assumed emission reduction rates of approximately 3 per cent per year between a 2015 peak and 2050 [47 fig. 2, p. 32].

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budgets (approx. 37% of not exceeding 2°C) owing to non-Annex 1 emissions both continuing with recent growth rates out to 2020 and peaking in 2025. The other surpassed the higher of the two cumulative budgets (approx. 50% of not exceeding 2°C) because, in addition to the emissions growth and peak years, post-peak emission reductions of 4–5% per year were insufficient to stay within the cumulative budget. Those pathways remaining within the lower budget required an immediate and rapid decline in Annex 1 emissions and an early peak in non-Annex 1 emissions, unless the latter's emission growth was constrained to rates much lower than historical trends (i.e. to 1%, compared with current growth of 3–4% per year [48]). In all cases, Annex 1 emissions continue to decline following the current economic downturn at rates in excess of 5 per cent per year. Given these pathways explicitly exclude non-CO_2 greenhouse gas emissions, the rates of reduction for CO_2 presented in table 1 illustrate the change necessary within the energy system primarily. Furthermore, figures 1 and 2 illustrate the need for complete decarbonization of the Annex 1 energy system by around 2050. For the higher (approx. 50%) chance of not exceeding 2°C, figure 2 and table 1 illustrate that a 5 year delay in the peak year for non-Annex 1 nations (from 2020 to 2025) forces a 2 per cent increase in reduction rates globally in addition to an immediate emission reduction for Annex 1 nations.

(*b*) *Basket of six* (*B6*)

When developing the B6 pathways (figures 3 and 4), it became apparent immediately that the 'low' IPCC cumulative emission value was not viable if non-Annex 1 emissions peak as late as 2020. Consequently, the minimum probability of not exceeding the 2°C threshold achievable in this scenario pathway set is 38 per cent. Moreover, given a significant portion of emissions are attributable to food production post-2050, this probability is likely to be a significant underestimate, with a more probable figure closer to 48 per cent. This result is in line with the scenario pathway analysis within Anderson & Bows [2]. For the IPCC's 'high' end of the range, emission reductions of 6 per cent per year for both Annex 1 and non-Annex 1 nations are necessary if non-Annex 1 emissions continue at recent growth rates and peak in 2020. However, if these rates are sustained for a further five years (i.e. to 2025), and non-Annex 1 post-peak reductions are 6 per cent per year or less, no emissions space remains for Annex 1 nations. Even if non-Annex 1 emissions grow at much slower rates to a 2025 peak, post-peak emission reductions of 4–5 per cent per year are still needed from the aggregate of all nations. Therefore, under the IPCC's higher budget, all viable scenario pathways exhibit emission reduction rates well in excess of those typically considered to be politically and economically feasible.

(*c*) *Orthodox*

In light of the recent Copenhagen negotiations, there continues to be an absence of any meaningful global action to mitigate emissions or set binding targets. Even if Annex 1 nations agree on the scale of necessary emission reductions, it is more

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probable that non-Annex 1 nations will set targets based on levels of carbon or energy intensity improvements. Although these will go some way towards addressing future high-carbon lock-in, it is unlikely that emission growth rates will be significantly moderated during the coming decade. To explore the implications of this, the two orthodox scenario pathways paint a picture of ongoing non-Annex 1 emission growth, slow action to mitigate emissions on the part of Annex 1 nations, and then sustained emission reductions at rates considered politically and economically feasible. Resulting cumulative emissions, while still within the bounds of possibility of not exceeding the 2°C threshold (8–12% chance), are more closely aligned with much higher climate change futures associated with at least 3–4°C of warming.

(*d*) *Simple and complex scenarios*

The scenarios developed in this paper are relatively contextual[24] and as such complement the wealth of scenarios from more non-contextual integrated assessment models.[25] However, while it may be argued that the latter approach benefits from greater internal consistency and more theoretically coherent parameters, the outputs are typically removed from the political and empirical reality within which responses to climate change are developed. For example, recent overviews of scenarios generated by a range of different international integrated assessment modelling communities [10,14] illustrate the non-contextual framing that typifies much of this form of analysis. Of the principal 450 ppmv scenarios reviewed, the majority had a global emissions peak in 2010, this despite irrefutable evidence to the contrary [48].[26] Over a third factored in negative emissions through the inclusion of geo-engineering in the form of 'biomass with carbon capture and storage' (CCS) technologies. These bio-CCS scenarios all included wider CCS facilities, yet were without detailed analysis of potentially significant constraints on storage capacity.[27] At least half of the scenarios relied on significant levels of 'overshoot' (between 500 and 590 ppmv CO_2e)[28] and

[24]Though constrained explicitly to consider top-down emissions only with coarse high-level divisions between food, deforestation, energy and industrial processes.

[25]Bottom-up and built on typically idealized inputs with only limited regard for 'real-world' constraints.

[26]While Köne & Büke's [48] paper was published after many of the scenarios referred to, the overarching data and trend lines underpinning Köne and Büke's analysis were available at the time many of the scenarios were developed.

[27]The inclusion of bio-CCS also demonstrates a degree of non-contextual engagement with technology. Aside from the considerable bio-energy debate surrounding the sustainability of biofuels, no CCS power plants have yet being built and consequently large-scale CCS remains a theoretical possibility with no operating experience of capture rates (though many of the component processes have undergone testing). Given the many unknowns around bio-CCS, it is perhaps surprising they are central to so many scenarios. This non-contextual approach to technology extends to nuclear power, included as a 'key energy supply technology' in all but one of the 450ppmv scenarios reviewed. Whilst sufficient uranium exists for moderate increases in conventionally fuelled reactors, significant ramping up of nuclear capacity is likely to require fast breeder reactors with major challenges associated with their widespread introduction; here too the integrated assessment modelling approach typically treats these wider concerns as exogenous and resolvable.

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several assumed fossil fuel CO_2 emissions from non-Annex 1 nations would exceed those from Annex 1 as late as 2013–2025 [14], despite the actual date being around 2006.[29]

The non-contextual framing of many complex modelling approaches (including integrated assessment modelling), allied with their inevitable opaqueness and often abstract and implicit assumptions, leaves space for the simpler, more transparent and contextual approach to scenarios presented in this paper. Making explicit the implications of particular assumptions (such as peak emission dates or very low probabilities of exceeding 2°C) provides insights that not only are intelligible to wider stakeholders and decision-makers, but can also provide 'contextual' parameters and constraints to more complex modelling approaches.

(*e*) *Development on the authors' 2008 paper*

Two years on from earlier analysis by Anderson & Bows [2], only the global economic slump has had any significant impact in reversing the trend of rising emissions. However, with Annex 1 and non-Annex 1 nations returning rapidly to their earlier economic and emissions trajectories and with the failure of Copenhagen to achieve a binding agreement to reduce emissions in line with 2°C, the prospects for avoiding dangerous climate change, if they exist at all, are increasingly slim. Furthermore, disaggregating global into Annex 1 and non-Annex 1 emission pathways only serves to exacerbate the scale of this disjuncture between the rhetoric and reality of mitigation. In both these regards and with the continued high-level reluctance to face the real scale and urgency of the mitigation challenge, the conclusions arising from this paper are significantly bleaker than those of the authors' 2008 paper.

6. Conclusions

Over the past five years a wealth of analyses have described very different responses to what, at first sight, appears to be the same question: *what emission-reduction profiles are compatible with avoiding 'dangerous' climate change?* However, on closer investigation, the difference in responses is related less to different interpretations of the science underpinning climate change and much more to differing assumptions related to five fundamental and contextual issues.

(1) What delineates dangerous from acceptable climate change?
(2) What risk of entering dangerous climate change is acceptable?
(3) When is it reasonable to assume global emissions will peak?
(4) What reduction rates in post-peak emissions is it reasonable to consider?
(5) Can the primacy of economic growth be questioned in attempts to avoid dangerous climate change?

[28]Overshoot scenarios remain characterized by considerable uncertainty and are the subject of substantive ongoing research (e.g. [49,50]).

[29]Within the integrated assessment modelling scenarios referred to, the division related to Annex B regions. For all practical purposes aggregated emissions related to Annex 1 are the same as those for Annex B.

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While (1) and, to a lesser extent, (2) are issues for international consideration,[30] the latter three have pivotal regional dimensions that, at their most crude level, can be understood in relation to Annex 1 and non-Annex 1 emission profiles.

In relation to the first two issues, the Copenhagen Accord and many other high-level policy statements are unequivocal in both their recognition of 2°C as the appropriate delineator between acceptable and dangerous climate change and the need to remain at or below 2°C. Despite such clarity, those providing policy advice frequently take a much less categorical position, although the implications of their more nuanced analyses are rarely communicated adequately to policy makers. Moreover, given that it is a 'political' interpretation of the severity of impacts that informs where the threshold between acceptable and dangerous climate change resides, the recent reassessment of these impacts upwards suggests current analyses of mitigation significantly underestimate what is necessary to avoid dangerous climate change [20,21]. Nevertheless, and despite the evident logic for revising the 2°C threshold,[31] there is little political appetite and limited academic support for such a revision. In stark contrast, many academics and wider policy advisers undertake their analyses of mitigation with relatively high probabilities of exceeding 2°C and consequently risk entering a prolonged period of what can now reasonably be described as extremely dangerous climate change.[32] Put bluntly, while the rhetoric of policy is to reduce emissions in line with avoiding dangerous climate change, most policy advice is to accept a high probability of extremely dangerous climate change rather than propose radical and immediate emission reductions.[33]

This already demanding conclusion becomes even more challenging when assumptions about the rates of viable emission reductions are considered alongside an upgrading of the severity of impacts for 2°C. Within global emission scenarios, such as those developed by Stern [6], the CCC [8] and ADAM [47], annual rates of emission reduction beyond the peak years are constrained to levels thought to be compatible with economic growth—normally 3 per cent to 4 per cent per year. However, on closer examination these analyses suggest such reduction rates are no longer sufficient to avoid dangerous climate change. For example, in discussing arguments for and against carbon markets the CCC state 'rich developed economies need to start demonstrating that a low-carbon economy is possible and compatible with economic prosperity' [8, p. 160]. However, given the CCC acknowledge 'it is not now possible to ensure with high likelihood that a temperature rise of more than 2°C is avoided' and given the view that reductions in emissions in excess of 3–4% per year are not compatible with economic growth, the CCC are, in effect, conceding that avoiding dangerous (and even extremely dangerous) climate change is no longer compatible with economic prosperity.

[30]Regions can evidently identify what may constitute dangerous within their geographical boundaries, but given many impacts (and the responsibility for them) extend well beyond such boundaries any regional assessment needs to be within the context of a more global perspective.
[31]If the impacts are to remain the principal determinant of what constitutes dangerous, then would it be more reasonable to characterize '1°C as the new 2°C'?
[32]Assuming the logic for the 2°C characterization of what constitutes dangerous still holds.
[33]With policies themselves lagging even further behind in terms of both actual reductions achieved or planned for.

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In prioritizing such economic prosperity over avoiding extremely dangerous climate change, the CCC, Stern, ADAM and similar analyses suggest they are guided by what is *feasible*.[34] However, while in terms of emission reduction rates their analyses favour the 'challenging though still feasible' end of orthodox assessments, the approach they adopt in relation to peaking dates is very different. All premise their principal analyses and economic assessments on the 'infeasible' assumption of global emissions peaking between 2010 and 2016; a profound departure from the more 'feasible' assumptions framing the majority of such reports. The scale of this departure is further emphasized when disaggregating global emissions into Annex 1 and non-Annex 1 nations, as the scenario pathways developed within this paper demonstrate.

Only if Annex 1 nations reduce emissions immediately[35] at rates far beyond those typically countenanced and only then if non-Annex 1 emissions peak between 2020 and 2025 before reducing at unprecedented rates, do global emissions peak by 2020. Consequently, the 2010 global peak central to many integrated assessment model scenarios as well as the 2015–2016 date enshrined in the CCC, Stern and ADAM analyses, do not reflect any orthodox 'feasibility'. By contrast, the logic of such studies suggests (extremely) dangerous climate change can only be avoided if economic growth is exchanged, at least temporarily, for a period of planned austerity within Annex 1 nations[36] and a rapid transition away from fossil-fuelled development within non-Annex 1 nations.

The analysis within this paper offers a stark and unremitting assessment of the climate change challenge facing the global community. There is now little to no chance of maintaining the rise in global mean surface temperature at below 2°C, despite repeated high-level statements to the contrary. Moreover, the impacts associated with 2°C have been revised upwards (e.g. [20,21]), sufficiently so that 2°C now more appropriately represents the threshold between dangerous and extremely dangerous climate change. Consequently, and with tentative signs of global emissions returning to their earlier levels of growth, 2010 represents a political tipping point. The science of climate change allied with emission pathways for Annex 1 and non-Annex 1 nations suggests a profound departure in the scale and scope of the mitigation and adaption challenge from that detailed in many other analyses, particularly those directly informing policy.

However, this paper is not intended as a message of futility, but rather a bare and perhaps brutal assessment of where our 'rose-tinted' and well intentioned (though ultimately ineffective) approach to climate change has brought us. Real hope and opportunity, if it is to arise at all, will do so from a raw

[34]The reference to 'feasible' technologies typically extends to carbon capture and storage, which, in 2010, remains untried for a large scale power station. Moreover, it is often allied with biomass combustion to provide 'negative' emissions (§5*d*). Without such negative emissions, several of the major analyses (e.g. [9,10]) will have increased cumulative emissions and hence further increased probabilities of exceeding 2°C (see also footnote 27).

[35]With the only exception being C+4 where Annex 1 emissions are stable until 2016, reducing thereafter.

[36]In essence, a planned economic contraction to bring about the almost immediate and radical reductions necessary to avoid the 2°C characterization of dangerous climate change whilst allowing time for the almost complete penetration of all economic sectors with zero or very low carbon technologies.

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and dispassionate assessment of the scale of the challenge faced by the global community. This paper is intended as a small contribution to such a vision and future of hope.

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Hydrology and hydraulic properties of a bedded evaporite formation

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Abstract

The Permian Salado Formation in the Delaware Basin of New Mexico is an extensively studied evaporite deposit because it is the host formation for the Waste Isolation Pilot Plant (WIPP), a repository for transuranic wastes. Geologic and hydrologic studies of the Salado conducted since the mid-1970s have led to the development of a conceptual model of the hydrogeology of the formation that involves far-field (i.e. beyond the disturbance created by the repository) permeability in anhydrite layers and at least some impure halite layers. Pure halite layers and some impure halite layers may not possess an interconnected pore network adequate to provide permeability. Pore pressures are probably very close to lithostatic pressure. In the near field around an excavation, dilation, creep, and shear have created and/or enhanced permeability and decreased pore pressure. Whether flow occurs in the far field under natural gradients or only after some threshold gradient is reached is unknown. If far-field flow does occur, mean pore velocities are probably on the order of a meter per hundreds of thousands to tens of millions of years.

Most hydraulic-test responses in the Salado do not appear to reflect radial flow, but instead imply subradial (e.g. intermediate between linear and radial) flow dimensions. We believe these subradial dimensions reflect channeling of flow through fracture networks, or portions of fractures, that occupy a diminishing proportion of the radially available space, or through percolation networks that are not 'saturated' (percolation terminology meaning fully interconnected). This is probably related to the directional nature of the permeability created or enhanced by excavation effects. Inferred values of permeability cannot be separated from their associated flow dimensions. Therefore, numerical models of flow and transport should include heterogeneity that is structured to provide the same flow dimensions as are observed in hydraulic tests. Modeling of the Salado Formation around the WIPP repository should also include coupling between hydraulic properties and the evolving stress field because hydraulic properties change as the stress field changes. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Evaporites; Hydraulic properties; Flow dimensions; Hydrology; Stress-dependent properties

1. Introduction

The hydrology of evaporite deposits is generally little studied and is poorly understood. The Permian Salado Formation in the Delaware Basin of New Mexico is one of the most extensively studied evaporite deposits in the world because it is the host formation for the Waste Isolation Pilot Plant (WIPP), a repository for transuranic wastes generated by the United States' defense programs. As part of WIPP site characterization, geologic and hydrologic studies of the Salado have been conducted since the mid-1970s. In the following paper, we describe our conceptual model for Salado hydrology and discuss the data that have been used to develop that model.

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We consider both the hydrology of the Salado in the far field, unaffected by the presence of the WIPP excavations, and in the near field or disturbed rock zone (DRZ) around the repository. We also discuss aspects of the conceptual model that are important to include in numerical models of Salado hydrology.

2. Salado geology

The Salado Formation is approximately 600 m thick at the WIPP site and lies approximately 260–860 m below ground surface. It is composed largely of bedded halite, with minor amounts of interspersed clay and polyhalite. The Salado also contains interbeds of anhydrite, polyhalite, clay, and siltstone. Many of these interbeds are traceable over most of the Delaware Basin. Jones et al. (1960) designated 45 of the continuous anhydrite and/or polyhalite interbeds as 'Marker Beds' (MB), and numbered these MB from 100 to 144, increasing downward. The WIPP facility horizon (the stratigraphic location of the underground excavations) lies between MB138 and MB139, approximately 655 m below ground surface.

A typical stratigraphic section of a 58-m interval of the Salado, centered approximately at the stratigraphic midpoint of the WIPP excavations, is shown in Fig. 1. Sixteen 'map units', numbered 0–15, and 39 other identifiable units have been described by Deal et al. (1989) and Roberts et al. (1999). The majority of the units is composed primarily of halite, and is differentiated principally on the basis of differing clay and polyhalite contents, which rarely exceed 5%. The halite units lacking integer map-unit designations are identified by H (pure halite), AH (argillaceous halite), or PH (polyhalitic halite) prefixes, followed by a number or letter ('m' for 'minus')—number combination representing that unit's position with respect to the base of the sequence, which was arbitrarily defined as the halite unit immediately underlying anhydrite 'c' and clay B. For example, AH-4 is the fourth argillaceous halite unit above the base of the sequence and H-m1 is the first halite unit below the base of the sequence. The remainder of the units are sulfatic interbeds, such as MB138 and MB139, and clay seams. The interbeds are composed primarily of anhydrite, with lesser amounts of polyhalite and halite.

Thinner sulfatic interbeds and a number of the more continuous clay seams have also been given letter designations (e.g. anhydrite a, clay B) to facilitate consistent referencing. These units are shown in Fig. 1. The stratigraphic positions of the WIPP excavations with respect to the designated map units are shown in Fig. 2.

3. Conceptual models

3.1. Far-field Salado hydrology

Our conceptual model for far-field Salado hydrology is as follows. Porosity of both halite and anhydrite is low, on the order of 0.01. All interconnected porosity is filled with brine containing dissolved gases, principally nitrogen. Because halite is a creeping medium, pore pressures are expected to be lithostatic, or very close thereto. Different layers have different permeabilities; anhydrites and clay-rich layers have the highest permeabilities and pure halites have the lowest permeabilities. Some halite beds may have no permeability because of inadequate connection of the pores. Anhydrite permeability derives from naturally occurring bedding-plane fractures (Borns, 1985). The pure halite layers with extremely low to non-existent permeabilities impede vertical flow of brine, so most flow through the Salado is horizontal, parallel to bedding. Within an individual bed, flow may be channelized into relatively high-permeability pathways created either by natural heterogeneity or by syndepositional dissolution troughs filled with pure halite (Powers and Hassinger, 1985) cutting across the bed that limit flow in certain directions. Gas-threshold (air-entry) pressures of the evaporites are high, probably exceeding the hydraulic-fracturing pressures, because of the very low permeabilities.

We assume that flow is driven by pressure gradients and follows Darcy's law, as in most porous media. However, as pointed out by Neuzil (1986), Darcy flow has never actually been demonstrated in low-permeability formations such as the Salado under natural low gradients. Other researchers (e.g. Swartzendruber, 1962; Pascal, 1981; Remson and Gorelick, 1982) have suggested that low-permeability media may have threshold gradients below which no flow can occur, perhaps related

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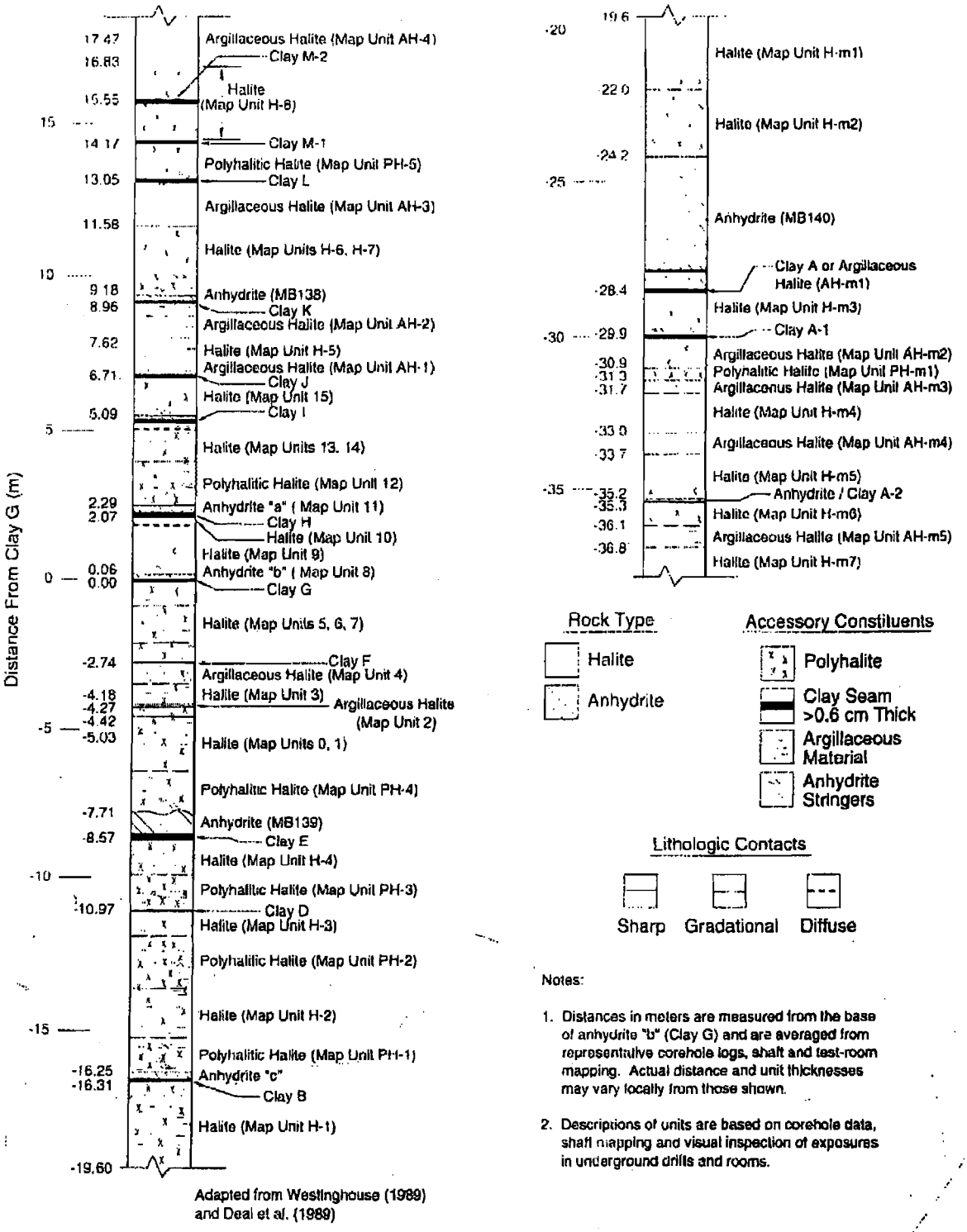


Fig. 1. Detailed stratigraphy near the WIPP underground facility.

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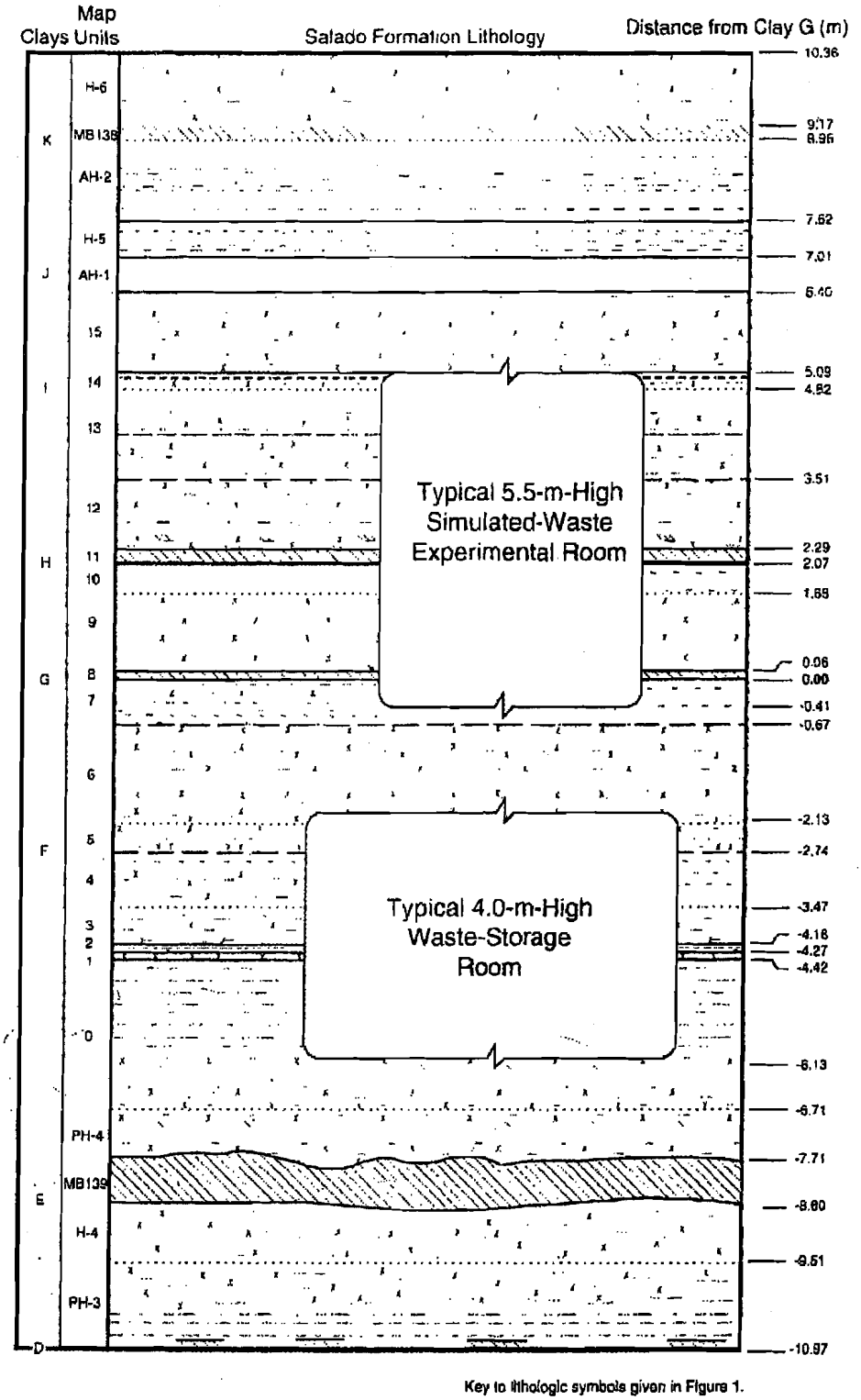


Fig. 2. Schematic of typical WIPP underground rooms showing stratigraphic positions.

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to capillarity or surface-tension effects in very small pores. Thus, Darcy flow in the far field is unproven. To whatever extent regional flow is occurring under the naturally occurring gradients, it is expected to be toward areas of lower overburden pressure. Flow is expected to be immeasurably slow, however. Given a halite permeability that we think might be representative of far-field conditions of 10^{-22}–10^{-21} m^2 (hydraulic conductivity of $\sim 10^{-15}$–10^{-14} m/s; see Section 5.3), a hydraulic gradient of 0.01, and a porosity of 0.01, brine would take between 3 and 30 million years to flow 1 m. In anhydrite, where the permeability might be 100 times higher, brine would still take 30,000–300,000 years to flow 1 m.

3.2. Excavation effects on near-field hydrology

When the WIPP repository was mined, the far-field hydrologic system was altered locally by a variety of mechanical and coupled hydraulic and mechanical processes. These 'excavation effects' are discussed below.

When an excavation is first mined, inelastic dilation (volume expansion) of the surrounding rock mass occurs as the rock expands into the newly created void volume. This dilation affects both the solid volume and pore volume of the rock. In part, the dilation is manifested as grain-boundary separation and readjustment. As the pores dilate, the fluid pressure in the pores decreases. If the pores dilate more than the brine can expand, partially saturated conditions may result. Gas may come out of solution as the pore pressure decreases, resulting in two-phase conditions.

Peach (1991) discussed the effects of dilation on halite permeability in terms of percolation theory. Under undisturbed conditions, the low porosity of halite may be too poorly connected to reach the percolation threshold—the minimum pore connectivity at which flow can occur. Without a throughgoing, interconnected pore network on the scale of measurement, a medium will show zero permeability. Given small amounts of dilation (≥0.05 vol%), however, Peach (1991) found that sufficient grain-boundary microfracturing occurs to create an interconnected pore network beyond the percolation threshold. From the percolation threshold, permeability increases rapidly with increasing dilation until the pore network is saturated (percolation terminology meaning fully interconnected), which occurs at some dilation less than 1%. Beyond the saturation point, increased dilation has little effect on permeability. Thus, dilation around an excavation can cause halite to shift from a condition in which permeability is effectively nonexistent to a condition with measurable permeability. The dilatancy of halite is enhanced by the presence of impurities (e.g. anhydrite, clay), so impure halite will dilate, and thereby increase in permeability, to a greater distance from an excavation than pure halite. Note that we do not apply this percolation model to anhydrite, in which flow occurs through naturally occurring fractures.

In addition to dilation, stress changes occur around the mined opening. The vertical load that had been borne by the removed rock is transferred to the pillars adjacent to the room, creating a compressive vertical stress concentration in the ribs of the excavation. This compressive stress may act to heal any grain-boundary separations that have occurred in halite, particularly if the pore pressure has decreased. At the same time, the horizontal stress at the excavation ribs is reduced to zero. In halite, the resulting deviatoric stress causes the rock to creep toward the excavation. Porosity and permeability are continually created as creep occurs. Close to the excavation where the most creep occurs, extensional strain fractures may develop parallel to the excavation surface.

Stresses are concentrated at the corners of an excavation, resulting in shear fracturing. Shear fractures are around the opening, creating an effective opening with a more mechanically stable elliptical cross section (Borns and Stormont, 1988, 1989). At WIPP, this idealized picture is complicated by the presence of layers with different properties, particularly anhydrite and clay interbeds (e.g. Munson, 1997; Chan et al., 1999). The shear fractures that form at the upper corners of WIPP excavations are upwards toward the nearest anhydrite/clay seam, typically anhydrite 'b'/clay G (Fig. 2). The anhydrite interbeds are stiffer than the overlying and underlying halite, and tend to separate from the halite along shear planes. With time, all of the rock inside the shear planes becomes decoupled from the surrounding rock mass. This sometimes leads to roof falls of all the rock between the roof of an excavation and clay G.

The permeability created (or enhanced) by excavation effects is not isotropic. Grain-boundary

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microcracking occurs predominantly in the direction of maximum compressive stress, while extension fracturing occurs parallel to an excavation face (perpendicular to the minimum principal stress). In addition, the vertical compressive stress in the ribs of excavations will tend to heal horizontal microfractures. Thus, permeability around excavations has strong directional dependency.

4. Hydraulic testing

Pressure-pulse, constant-pressure flow, and pressure-recovery tests were performed between 1988 and 1995 in boreholes drilled from within the WIPP excavations to evaluate the hydraulic properties controlling brine flow in the vicinity of the repository. Test locations are shown in Fig. 3. Interpretations of the tests using the model GTFM (Pickens et al., 1987) were reported by Beauheim et al. (1991, 1993), Domski et al. (1996), and Roberts et al. (1999).

The tests were conducted in boreholes drilled to a variety of distances and in different orientations with respect to the underground excavations. After drilling, the holes were filled with native Salado brine and test tools with multiple packers were installed. The bottom-hole interval was the primary test zone in each hole, while the intervals between packers served as either guard zones (to guard against leaks) or secondary test zones. Hydraulic testing commenced after an initial pressure-buildup period. Two primary groups of tests were performed. One set of tests, involving 15 boreholes, was performed to determine how hydraulic properties were affected by the excavation of a cylindrical opening, Room Q (Fig. 3). The other set of tests was performed in 12 boreholes drilled at different locations in the WIPP excavations. These tests provided information about hydraulic properties around existing excavations at the time of testing.

A third set of tests involving 12 test holes called the Small-Scale Mine-By experiment was performed by Stormont et al. (1991a,b). The purpose of these tests was to determine how the drilling of a 96.5-cm-diameter hole would affect hydraulic properties around the hole. Half of these tests were conducted using brine and the other half were conducted using gas.

Before discussing the results of the three testing programs, we will introduce the concept of flow dimensions. Consideration of flow dimensions affects both the estimates of hydraulic properties inferred from hydraulic tests and the conceptualization of how those properties are distributed in space.

4.1. Flow dimensions

Hydraulic-test-interpretation methods have traditionally assumed that flow occurs radially toward or away from test boreholes, and that the flow fills all of the available space. In highly heterogeneous and/or fractured systems, particularly around an excavation where the stress field is changing in both time and space, these assumptions may not be valid. Notable attempts to expand well-test-interpretation methodologies to characterize non-radial flow can be found in Black et al. (1986), Barker (1988), Noy et al. (1988), and Doe (1991), where the concept of a flow dimension (n) is introduced. Barker (1988) discussed flow systems with constant hydraulic conductivity (K) and specific storage (S_s) where the flow dimension of the system was related to the power by which the flow area changed with distance from the source and n described the geometry of the system. The flow area in this formulation is given by

$$\text{Area}(r) = b^{3-n}\frac{2\pi^{n/2}}{\Gamma\left(\frac{n}{2}\right)}r^{n-1} \quad (1)$$

where n is the flow dimension, b, the extent of the flow zone, L, Γ, the gamma function, and r is the radial distance from borehole, L.

The flow dimension n is related to the power-law relationship between flow area and radial distance from the borehole. The flow dimension is defined as the power of variation plus one. For example, the relationship between flow area and distance in a standard radial system is given by

$$\text{Area}(r) = 2\pi rb \quad (2)$$

The flow area is seen to vary linearly with distance (r^1), making the flow dimension, by definition, two. All of the diagnostic methods used to deduce radial flow, i.e., the shapes of various type curves, depend only on the relationship between flow area and distance (r). The shapes of the type curves are independent of the constant $2\pi b$, so they provide no

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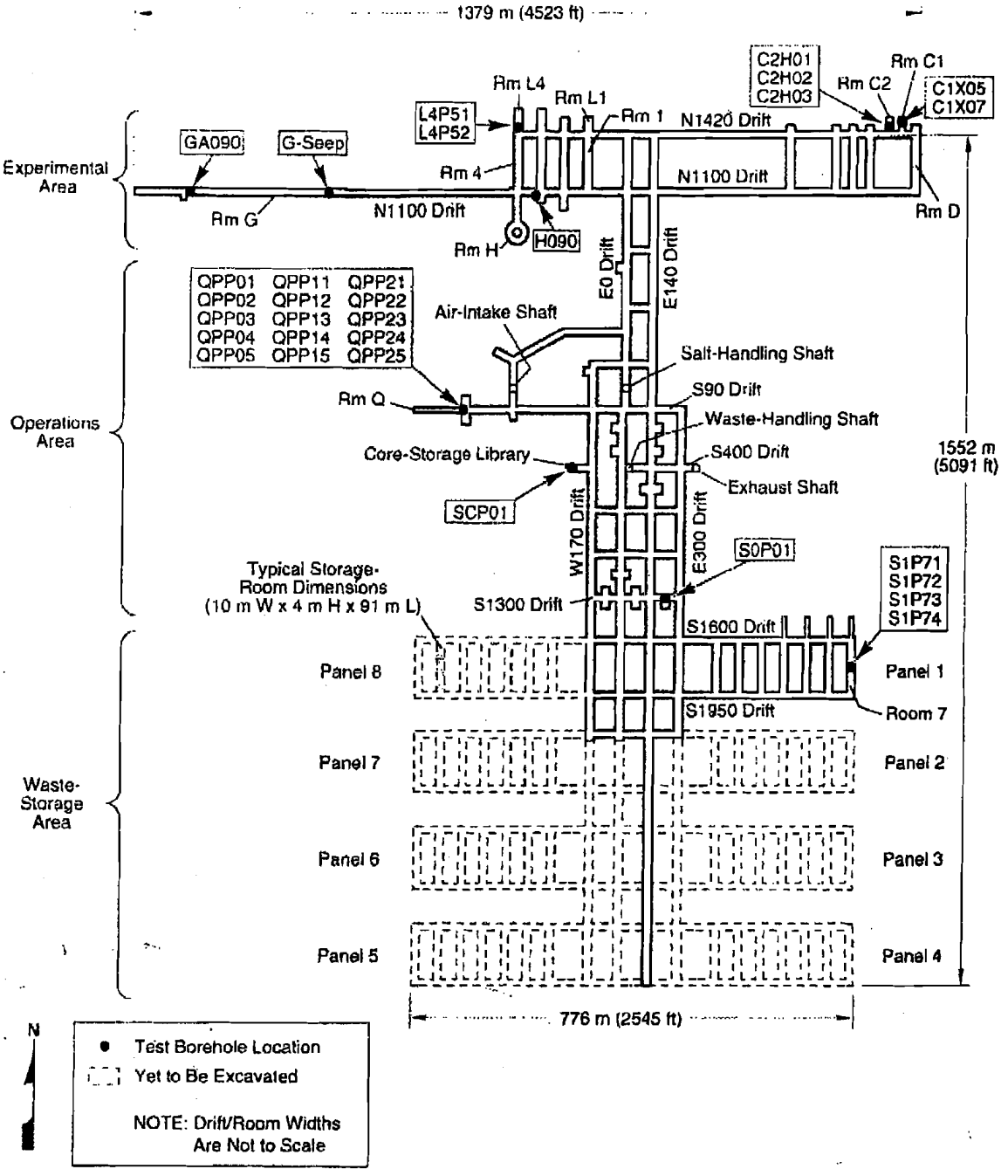


Fig. 3. Map of the WIPP underground facility showing test locations.

information on the degree to which the flow system fills the available space.

Roberts et al. (1999) showed that the dimensionality of flow can be deduced for any type of test from diagnostic plots of pressure and/or flow-rate changes and their derivatives. They interpreted flow as being non-radial in most of the Salado intervals in which hydraulic tests were performed. Of the 16 test

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responses they considered, they found flow to be subradial in nine cases, superradial in five cases, and radial in only two cases. Subradial (<2) flow dimensions, such as those interpreted from the tests of MB138 in L4P52 and S1P74 and of clay J in S1P74, are consistent with a medium in which fractures or pores are poorly interconnected or a medium in which flow is channeled through those portions of fractures having the largest apertures. In either case, the fractures or pores involved in flow occupy a proportion of the radially available space that diminishes with distance from the test hole. A superradial (>2) flow dimension suggests a system in which fracture/pore connectivity and/or density increase(s) with distance, or in which the space available for flow is expanding in a third dimension (e.g. spherical flow).

These results provide information useful in understanding flow through the Salado. As discussed in detail in Roberts et al. (1999), however, flow dimensions are somewhat problematic in that radial (dimension = 2) flow in a system with distance-varying hydraulic parameters cannot be distinguished from non-radial flow in a system with constant hydraulic parameters (in a single-well test). In addition, time-varying (or pressure-dependent) properties can be difficult to distinguish from spatially varying properties. To deal with these ambiguities, the concept of variable flow dimensions was broadened to include the non-unique combinations of temporal and spatial variations in flow geometries and hydraulic parameters. The baseline analysis of any test could then be transformed into different, non-unique combinations of geometries and hydraulic parameters as desired.

All of the excavation effects described above are location-specific and time-dependent and affect flow dimensions around an excavation in a variety of ways. If hydraulic properties in an individual layer change with distance from an excavation, a hydraulic test conducted in that layer will likely show a non-radial flow dimension. Whether the specific flow dimension is greater or less than radial will depend on the specific spatial pattern of variation of hydraulic properties. If a propagating pressure transient encounters a region of decreased permeability, the flow dimension will decrease, while a region of increased permeability will have an opposite effect. Fractures connecting two permeable layers that are otherwise separated will tend to increase the flow dimension. In a percolation network, the flow dimension should increase as the connectivity of the network increases. Thus, we might expect to see an increase in flow dimension in halite that has undergone dilation close to an excavation compared to the same halite at a greater distance from an excavation, unless the new pore connectivity is highly directional.

Flow dimensions that change as the volume of influence of a test expands should be expected. For instance, stress relief directly above or below an excavation may result in a zone of increased fracturing (and/or permeability) within the 'footprint' (vertical projection) of the excavation, with less fracturing (lower permeability) under the ribs of the excavation. When a propagating pressure transient reaches some type of discontinuity that restricts flow, such as a zone of decreased permeability or, in the extreme, a no-flow boundary, the flow dimension initially decreases rapidly. Thus, a rapid transition to a sublinear to negative flow dimension is best interpreted as a qualitative indication of a sudden reduction in permeability and/or flow area at some distance from the test hole. With time, the flow dimension will increase to a value representing the rate at which the permeability-area product continues to increase as the pressure transient propagates further in other directions (i.e. away from the 'boundary'). The flow dimensions from the first and second constant-pressure-withdrawal (CPW) tests of H-m2 in L4P51, respectively, illustrate these points. The flow dimension was initially between 1.5 and 1.8 during both tests, reflecting slightly subradial to radial conditions. The flow dimensions then decreased to negative values, reflecting some restriction to flow with distance from the borehole. After a transition period, the flow dimension rose and stabilized at a value greater than one but less than the initial value, reflecting the loss in permeability and/or area.

Argüello (1991) showed that stress relief is not uniform below an individual room, but is greater where the room intersects a drift and is less at the back of a room where no further excavation has occurred. A test conducted near the front of a room might, therefore, show one flow dimension until the pressure transient propagated into the higher permeability region below the intersection of the room with

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its access drift, at which time a higher flow dimension would be evident. The tests of MB140 in L4P51 may provide an example of this. Conversely, a test conducted near the back of a room might show a decreasing flow dimension for some period of time as the pressure transient propagates into the lower permeability rock beyond the footprint of the excavation. At some later time, the flow dimension might increase if the pressure transient propagated into a higher permeability region toward the front of the room. Flow dimensions should also be expected to change with time where hydraulic properties are pressure-dependent. Non-uniform (i.e. high-gradient) pressure fields in regions with varying hydraulic properties must also affect inferred flow dimensions.

4.2. Tests around Room Q

Room Q was mined at the western end of the S90 drift in an area that should have been minimally, if at all, affected by the presence of the other WIPP excavations (Fig. 3). Room Q was mined using a tunnel-boring machine to create a 2.9-m-diameter cylindrical room 109 m long. Before the room was mined, 15 boreholes were drilled into the west rib of the alcove at the end of the S90 drift and instrumented to allow pore pressure and permeability testing before and after the mining. The holes were drilled so that they terminated in three lines, comprising five holes each, vertically above (QPP01-05), vertically below (QPP11-15), and horizontally north (QPP21-25) of the eventual centerline of the room (Fig. 4). All of the boreholes terminate 22.9 m along the length of the room in a plane normal to the axis of the room. In each of the three arrays, the boreholes were designed to terminate at distances of approximately 2.4, 3.3, 4.6, 7.6, and 13.7 m from the centerline of the room. The tests conducted in these holes before Room Q was mined should provide the best representation of far-field properties of any of the permeability tests performed. The parameter values presented below were derived by Domski et al. (1996) assuming a flow dimension of two; no flow-dimension analysis of these tests has been performed.

Four anhydrite layers were isolated in the Room Q boreholes: MB138 (QPP01), MB139 (QPP13), anhydrite b (QPP03), and anhydrite c (QPP11). All four anhydrites showed immediate pressure-buildup responses when the test zones were shut in. Estimated pre-mining pore pressures of MB138, MB139, and anhydrite b ranged from 12.4 to 14.8 MPa (Fig. 4). The anhydrite c test interval was not shut-in long enough for an estimate of the pre-mining pore pressure to be made. The inferred pre-mining permeabilities of MB139 and anhydrite b were 6×10^{-20} and 8×10^{-20} m^2, respectively. The pre-mining data from MB138 and anhydrite c were inadequate for permeability estimation. After Room Q was mined, estimated pore pressures decreased and inferred permeabilities increased insignificantly. Post-mining pore pressures for the four anhydrite layers ranged from 6.9 to 10.4 MPa. Inferred permeabilities for both MB139 and anhydrite b were 8×10^{-20} m^2, and the permeability of MB138 was inferred to be 1×10^{-19} m^2 (Fig. 4).

Twelve halite intervals were isolated in the Room Q boreholes. Of these, six (map units 12 and 13 [QPP02], 6 [QPP05], H-1 [QPP11], PH-4 [QPP14], 0 and PH-4 [QPP15], and 2 and 3 [QPP21]) showed no clear pore pressure or permeability before Room Q was mined. The remaining six intervals showed clear evidence of both permeability and pore pressure. These intervals (map units 6 and 7 [QPP04], H-3 [QPP12], and 2 and/or 3 [QPP22-25]) had apparent pore pressures of approximately 9–10 MPa. The only pre-mining permeability that could be estimated with confidence was 3×10^{-22} m^2 for H-3 in QPP12. Domski et al. (1996) also attempted simulations of the pressure data from the intervals that showed no clear pore pressure or permeability. They found that those intervals could have permeabilities on the order of 10^{-24}–10^{-22} m^2 and not show obvious pressure-buildup responses toward the ambient pore pressure over the 10s of days that pressure measurements were made. Thus, small but non-zero permeabilities are not inconsistent with the observed data.

After Room Q was mined, all of the halite intervals showed clear evidence of pore pressure and permeability. With the exception of H-3 in QPP12, all halite intervals for which pre-mining pore pressures could be estimated had lower pore pressures after mining. The intervals for which pore pressures could only be estimated after mining had extrapolated pore pressures of 9.6 MPa or less. Pore pressures appeared to decrease with increasing proximity to Room Q. In some intervals, post-mining pore pressures appeared

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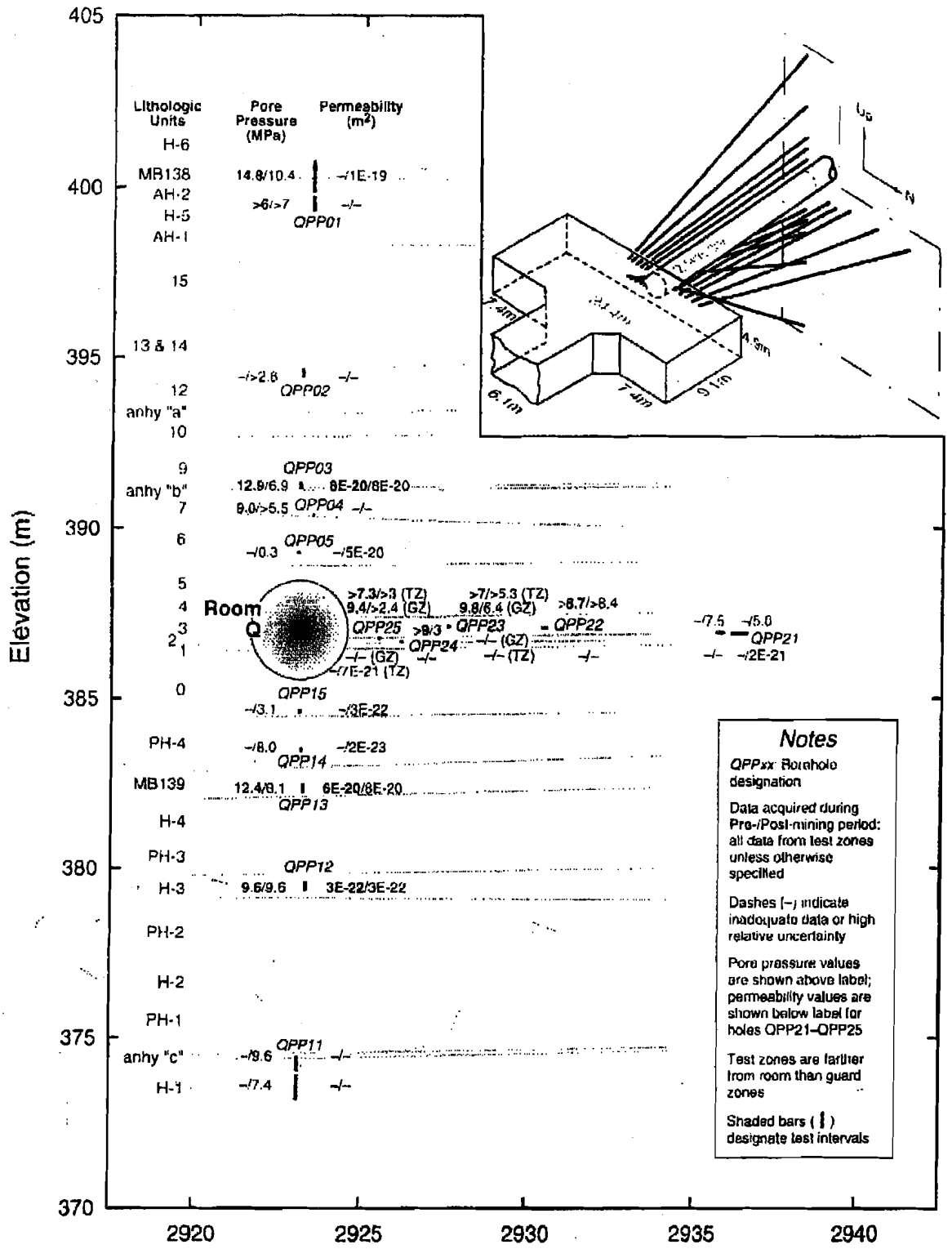


Fig. 4. Stratigraphic locations of test boreholes around Room Q and interpreted hydraulic properties.

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to continue to decrease with time. The post-mining permeabilities that could be estimated for halite intervals ranged from 2×10^{-23} to 5×10^{-20}; m^2 (Fig. 4). The permeability of the H-3 interval in QPP12 did not appear to change as a result of mining Room Q. Comparing the post-mining responses of the other halite intervals to the pre-mining responses, Domski et al. (1996) concluded that permeabilities had increased by at least two orders of magnitude.

The majority of the post-mining extrapolated pore pressures ≥6 m from the surface of Room Q (>5 radii from the room center) were approximately between 9 and 10 MPa. The pore pressure in QPP12 before mining also fell in this range. Perhaps this pore pressure reflects the mean stress at a distance of 23 m from the instrument alcove at the end of the S90 drift with no influence from Room Q. Two to three meters from the surface of Room Q (2.1–3.3 radii), post-mining pore pressures were 3–8 MPa, and within 1 m of Room Q (<1.7 radii), pore pressures were 0.3–3 MPa.

4.2.1. Summary of Room Q observations

The pre-mining observations around Room Q do not provide a simple picture of far-field hydraulic properties. All four of the anhydrite intervals tested showed permeability and pore pressure. Half (six) of the halite intervals tested showed permeability and pore pressure, and half did not. Extrapolated pore pressures in the six permeable halite intervals were only 9–10 MPa, not the 15 MPa estimated as the undisturbed lithostatic load at the WIPP horizon (Wawersik and Stone, 1989). Thus, stress relief related to the presence of the WIPP excavations may have affected all of the test locations even before Room Q was mined. Extrapolated pore pressures in the anhydrites (12.4–14.8 MPa) were closer to the estimated lithostatic pressure than those in the halite, suggesting that anhydrite may be less sensitive to the effects of mining on permeability. No conclusions can be drawn about the effects of mining on flow dimensions because no flow-dimension analysis has been performed of these tests. Halite pore pressures generally increased with distance from Room Q.

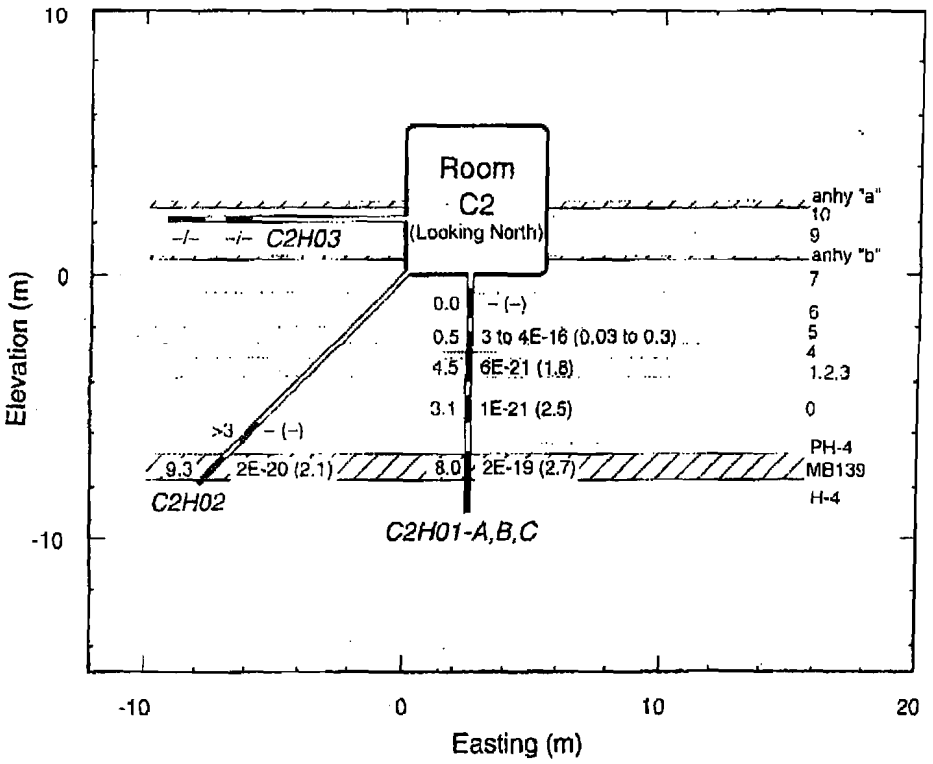
4.3. Tests at other locations

Forty-three intervals were isolated and monitored and/or tested in 12 boreholes drilled at various locations in the WIPP excavations (Fig. 3). Twenty of the intervals included anhydrite layers, and the other 23 intervals included different halite layers. The data from these intervals are discussed and interpreted in Beauheim et al. (1991, 1993) and Roberts et al. (1999). These tests were conducted at various distances and orientations around excavations of different sizes and ages. Thus, the results represent a combination of effects not easily disentangled.

Four of the intervals would not hold brine under pressure: C2H01-A guard zone (map unit 6), S1P71-A guard zone (MB139), and S1P73-A guard zone (anhydrite b) and test zone (anhydrite a). The C2H01-A and S1P71-A guard zones were 0.5–1.6 and 1.2–2.3 m, respectively, below the floors of excavations (Figs. 5 and 6). The S1P73-A guard and test zones were 1.5–2.6 and 3.4–4.8 m, respectively, directly above the roof of Room 7 in Panel 1 (Fig. 6). Floor heave at the first two locations and roof sag at the last location probably increased permeability and porosity beyond the capacity of the formation to keep it filled with brine.

Three of the intervals showed no pressure response indicative of permeability or pore pressure: C2H03 guard zone and test zone (both map unit 9), and SCP01-A guard zone (map unit PH-4). The test and guard zones in C2H03 were 7.9–9.1 and 5.9–6.9 m, respectively, from the rib of Room C2 (Fig. 5). The guard zone in SCP01 was 8.8–9.9 m from the core-

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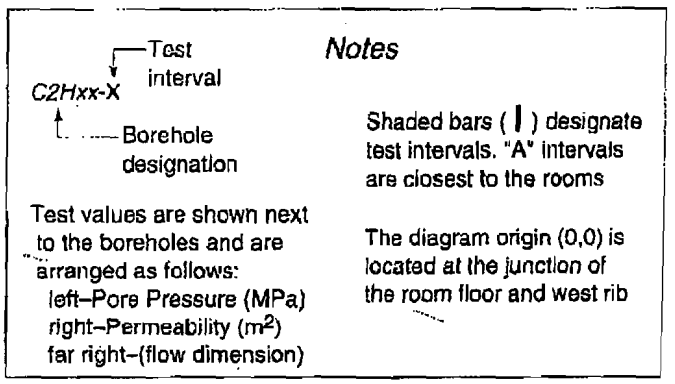


Fig. 5. Stratigraphic locations of test boreholes around Room C2 and interpreted hydraulic properties.

(six halite and 12 anhydrite intervals) and pore pressures were estimated (or bounded) for 31 intervals (15 halite and 16 anhydrite intervals). Estimated halite permeabilities ranged from 1×10^{-21} m^2 in the C2H01-B test zone (map unit 0), 4.5–5.6 m below Room C2, to 3×10^{-16} m^2 in the C2H01-A test zone (map units 4 and 5), 2.1–2.9 m below Room C2 (Fig. 5). Estimated anhydrite permeabilities ranged from 2×10^{-20} m^2 in the C2H02 test zone (MB139), 9.5–10.7 m from Room C2 in a borehole angled downward under the rib, to 9×10^{-18} m^2 in the SCP01-A test zone (MB139), 10.7–14.8 m below and away from a back corner of the core-storage library. Nonzero halite pore pressures ranged from 0.5 MPa in the C2H01-A test zone (Fig. 5) to 8.7 MPa in S1P74-B test zone 2 (map units AH-1 [clay J] and H-5), 13.2–14.3 m

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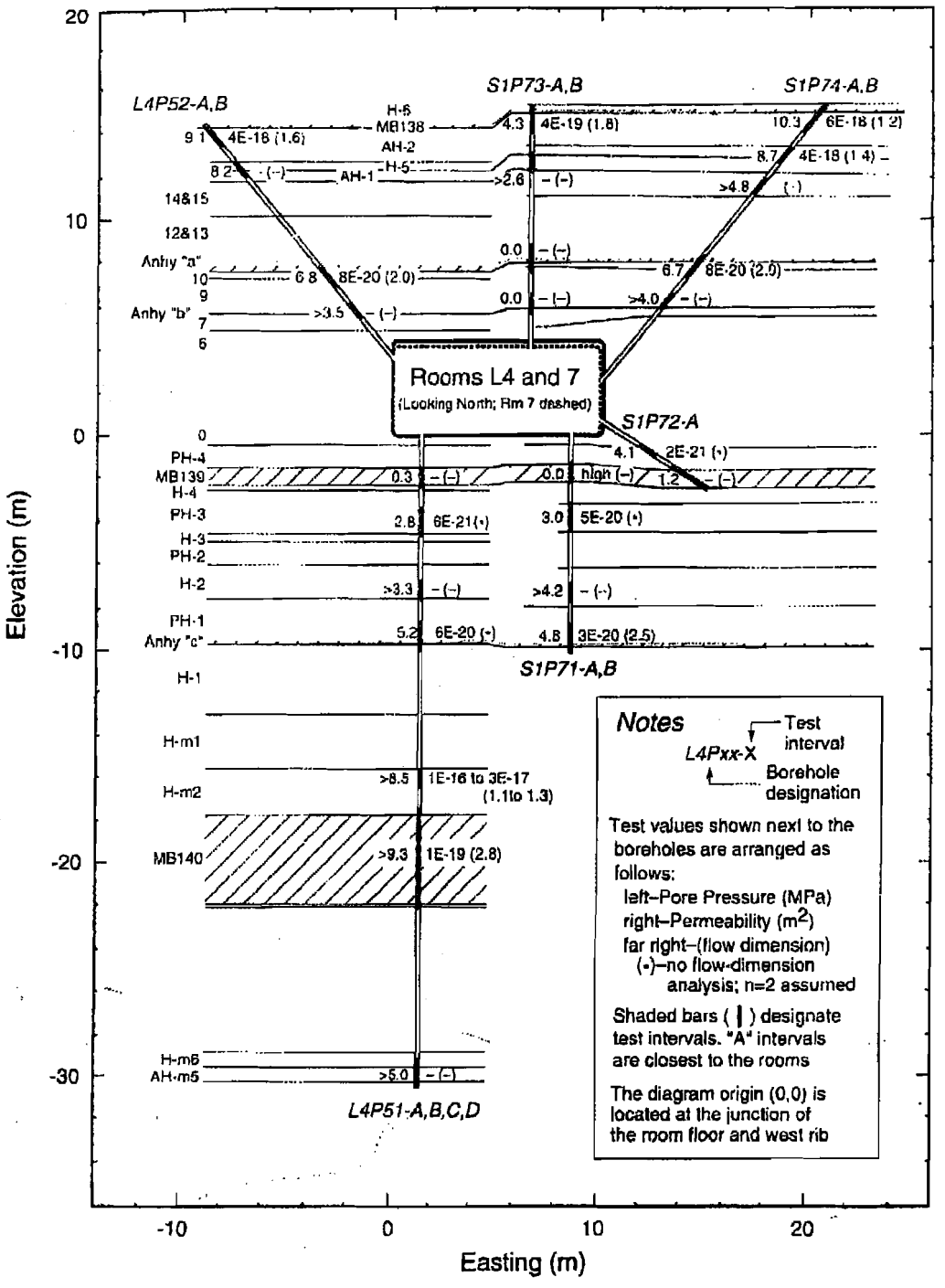


Fig. 6. Stratigraphic locations of test boreholes around Room L4 and Room 7 in Waste Panel 1 and interpreted hydraulic properties.

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angled upwards and away from Room 7 in Panel 1 (Fig. 6). Non-zero anhydrite pore pressures ranged from 0.3 MPa in the L4P51-A guard zone (MB139), 1.5–2.4 m directly below Room L4 (Fig. 6), to 13.5 MPa in the SCP01-A test zone.

In some cases, permeabilities were found to be dependent on the pressures at which the tests were conducted. As the test fluid pressure increased, the effective stress decreased and permeability increased. This is interpreted as fracture apertures increasing with decreasing effective stress. Pressure-dependent permeability was observed in both anhydrite and halite layers.

4.4. Small-scale Mine-by

Stormont et al. (1991a,b) performed an experiment designated the Small-Scale Mine-By to determine the effects of excavation on fluid saturation and permeability of the surrounding rock. They drilled an array of 12 4.8-cm-diameter boreholes to a depth of 8 m below Room L1 (Fig. 3) at different radial distances from where they would later drill a 96.5-cm-diameter hole. They isolated the lower 65 cm of each borehole (map unit H-2) and filled six of the holes with brine and six with gas, all pressurized to 2 MPa. Testing showed brine pore pressures of 2.7–3.6 MPa, brine permeabilities ranging from 1×10^{-22} to 2×10^{-20} m^2, and zero permeability to gas. After the 96.5-cm hole was drilled in the center of the test array, additional tests were performed in the boreholes. These tests showed that permeabilities within approximately two radii ($2r$) of the center of the 96.5-cm hole increased with proximity to the hole, with a maximum increase of nearly five orders of magnitude to 9×10^{-16} m^2 at $1.25r$. Pore pressures were reduced out to $3r$. Within approximately $1.5r$, partially saturated conditions and measurable gas permeability developed.

The tests described by Stormont et al. (1991a,b) were all conducted over an approximately 250-day period after the 96.5-cm hole was drilled, so did not evaluate any continuing time-dependence of hydraulic properties. The low initial pore pressures also indicate that the test horizon had been affected by stress relief resulting from the excavation of Room L1. Thus, the responses observed by Stormont et al. (1991a,b) were probably superimposed on an already-disturbed rock mass. Nevertheless, the test results clearly showed the development of a partially saturated zone around the 96.5-cm hole, increased permeability, and decreased pore pressure.

5. Observed spatial variations in hydraulic properties

The values of permeability and pore pressure inferred from the tests in the WIPP excavations are discussed below in the context of the foregoing discussion and plotted versus distance from an excavation. We cannot be certain that any of our test results are representative of conditions in the far field, completely unaffected by the presence of the WIPP excavations. The permeability of anhydrite is typically higher than that of halite. Pore pressure is demonstrably related to distance from an excavation.

5.1. Permeability

Fig. 5 shows the intervals tested in boreholes drilled from Room C2 and the properties inferred from the tests. The tests were all performed roughly 4.5–5.5 years after the mining of Room C2. In MB139, both the permeability and flow dimension were higher directly beneath the room (C2H01-C) than beneath the room pillar (C2H02). This probably reflects fracture dilation and/or increased fracturing due to stress relief directly beneath the room. In contrast, halite permeability decreased while the flow dimension increased with distance below the room. We speculate that excavation effects caused increased, but directional, permeability close to the room. The high flow dimension (2.5) observed in the C2H01-B test zone may indicate that the tested unit, map unit 0, has little anisotropy between horizontal and vertical permeability and that sections of the unit above and below the isolated interval contributed to the observed response. No pore-pressure response indicative of permeability was observed in the clean halite of map unit 9 in the room pillar (C2H03).

Fig. 6 shows the intervals tested in boreholes drilled from Rooms L4 and 7 (Waste Panel 1) and the properties inferred from the tests. MB138 had the lowest permeability and the highest flow dimension where it was tested directly above a room (S1P73-B). We would have expected to observe both the highest

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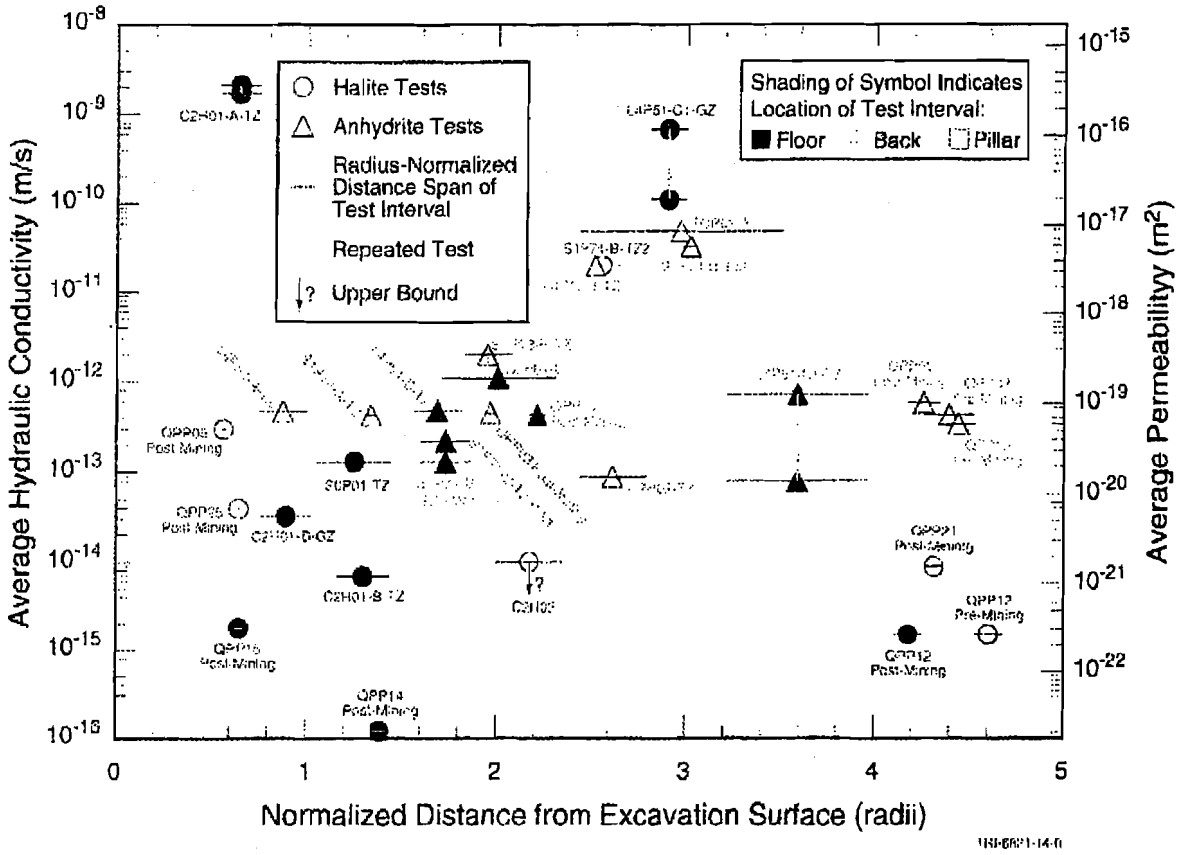


Fig. 7. Interpreted average permeabilities versus radius-normalized distances from excavations.

permeability and flow dimension in this position because of stress relief. However, the S1P73-B testing was performed approximately 3.2 years after the excavation of Room 7, whereas the S1P74-B and L4P52-B tests of MB138 above room pillars were performed approximately seven and four years after excavation of Rooms 7 and L4, respectively. Hence, the age of the excavations at the time of testing may have had some effect on the results. The units that were tested in two boreholes with similar orientations generally had similar permeabilities and flow dimensions. The L4P51-B and S1P71-B tests of anhydrite c, which were performed when the rooms were of similar ages (Room L4 was 1.7–2.6 years old at the time of testing while Room 7 was 1.7–2.2 years old), provided similar results. The L4P52-A and S1P74-A tests of anhydrite a provided similar results, even though Room L4 was 2.2–3.2 years old at the time of testing while Room 7 was 4.4–5.3 years old. The largest difference in permeabilities, nearly an order of magnitude, was observed in the L4P51-A and S1P71-A tests of map unit PH-3. The tests were performed at similar times relative to the ages of the rooms (9–15 and 8–13 months), so we attribute the difference in permeabilities to natural heterogeneity.

Fig. 7 presents a plot of average permeabilities versus radius-normalized test-interval distances from an excavation from GTFM simulations of the tests discussed in Beauheim et al. (1991, 1993), Domski et al. (1996), and Roberts et al. (1999). The distances were normalized by dividing the distance of each test interval along its borehole by the radius of the room in which the borehole originates, where the room radius is defined as one-half the diagonal distance across the room in cross section. (Distances for the QPPxx test intervals are normalized with respect to either the instrumentation alcove from which the holes were drilled or Room Q, whichever was closer in terms of

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radii at the time of testing.) The permeabilities of several of the tested units shown on Fig. 7 are believed to be pressure-dependent. The permeabilities shown on Fig. 7 for these tests are the permeabilities corresponding to the static pore pressures in the tested units prior to testing. Testing sequences performed in the L4P51-C1 guard zone and L4P51-C2 test zone 2 were tests of the same halite interval over different time periods, so the estimated permeability values are shown as a range for a single interval on the figure. Ranges are also shown for other intervals (e.g. MB140 in L4P51) for which different permeability estimates were obtained.

Fig. 7 shows 14 values of halite permeability and 16 values of anhydrite permeability. No correlations are evident between estimated halite or anhydrite permeability and radius-normalized distance from an excavation. The lowest estimate of halite permeability, 2×10^{-23} m^2, is from QPP14 after the mining of Room Q, approximately 1.4 room radii from the excavation. All halite permeabilities from test intervals two or more room radii from an excavation are higher than this value. The highest halite permeability estimate, 3×10^{-16} m^2, is from the C2H01-A test zone, approximately 0.6 room radii below an excavation. The lowest estimate of anhydrite permeability, 2×10^{-20} m^2, is from the C2H02 test zone, approximately 2.4–2.8 room radii from the excavation in a borehole angled downward under the rib. All five estimates of anhydrite permeability from distances greater than three room radii, both in angled and vertical boreholes, are greater than this value. The highest estimate of anhydrite permeability, 9×10^{-18} m^2, is from MB139 in the SCP01-A test zone, approximately 2.4–3.5 room radii below and beyond an excavation.

No correlations between permeability and distance from an excavation can be defined from Fig. 7 even when the angled-hole tests are considered separately from the vertical-hole tests. This is not to argue that permeability is *not* affected by the excavations. As discussed in Section 3.2, changes in the stress field around excavations likely cause both increases and reductions in permeability at different locations and times. But both halite and anhydrite permeabilities seem to range over several orders of magnitude just because of variations in mineralogy and other natural heterogeneity. Excavation-induced changes superimposed on this natural variation cannot be identified without pre- and post-excavation testing at each specific location.

As noted by Beauheim et al. (1993), estimated permeabilities such as those presented in Fig. 7 represent average values assuming that the tested intervals are homogeneous. If the observed responses are dominated by singular features (such as fractures) rather than by uniform properties, then the average permeability values shown in Fig. 7 might not be meaningful. Another factor complicating the comparison of permeability values is the relationship between permeability and flow dimension. The expression 'flow dimension' is used in this paper to represent the combined effects of changes in permeability and flow geometry. Thus, the reported value of permeability depends on the value used for flow dimension. For a given response, as the value of flow dimension used to interpret that response increases, the estimated permeability decreases, and vice versa. Even when flow dimension is clearly defined, we have no way of knowing without additional information if the dimension is caused by changes in permeability or changes in the geometry of flow. The reported permeability values are based on the following assumptions and are estimated using a multi-step analysis process. The measured formation response is matched initially using constant values of K and S_s and distance-varying n [$n(r)$], if necessary. The flow dimension in the next step is then assumed to be constant and equal to the late-time value determined in the previous step. Corresponding $K(r)$ and $S_s(r)$ functions are calculated such that the simulated response is identical to that obtained with $n(r)$ and constant K and S_s. The late-time values of $K(r)$ and $S_s(r)$ are constants that correspond to the specified value of n. These late-time values of K and S_s are the reported values, assumed to be the representative values beyond the DRZ (skin) around the test borehole. These assumptions may or may not be valid.

Only five of 14 halite permeabilities are equal to or greater than 10^{-20} m^2: those from L4P51-C1-GZ, C2H01-A, S1P74-B-TZ2, QPP05 post-mining, and S0P01-TZ. The L4P51-C1 guard zone was unlike any other zone tested and the reason for high permeability in halite H-m2 is unknown. The other four halite permeabilities greater than 10^{-20} m^2 all come from test intervals that are within approximately 2.6

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room radii of an excavation and/or contain significant clay seams. The C2H01-A test interval was approximately 0.6 room radii below the floor of Room C2, a location where excavation-induced disturbance would be expected. The C2H01-A tests were also the first of the permeability tests to be performed, and later experience showed that pulse tests conducted, like these, over a 0–3.5 MPa absolute pressure range are likely to be significantly affected by pressure-dependent test-zone compressibility. The data necessary to evaluate test-zone compressibility were not collected during the C2H01-A testing and, therefore, the parameters estimated from those tests are considered to have high uncertainty. The S1P74-B test zone 2 interval was approximately 2.5 room radii from the excavation, but included AH-1, the most clay-rich halite interval near the repository horizon. The QPP05 test interval was less than 0.6 room radii from Room Q, and the S0P01 test interval, 1.0–1.4 room radii from an excavation, included clay D.

Permeability values for anhydrite ranges approximately from 10^{-20} to 10^{-17} m^2. The three values greater than 10^{-18} m^2 were from tests conducted in boreholes angled away and at distances of 2.4 or more room radii from the excavations (SCP01-A, S1P74-B, and L4P52-B), suggesting that the inferred high permeabilities are not necessarily caused by responses to the excavations, but may be representative of far-field properties.

5.2. Pore pressure

Fig. 8 presents a plot of estimated formation pore pressures versus radius-normalized test-interval distances from an excavation for 40 halite intervals and 26 anhydrite intervals (Beauheim et al., 1991, 1993; Domski et al., 1996; Roberts et al., 1999). The pore pressures were estimated from GTFM simulations or extrapolated from maximum observed pressures in a zone for all of the Salado permeability tests. A general trend of increasing pore pressure with increasing distance from an excavation can be seen for both anhydrite and halite intervals. Figs. 4–6 show the same pattern of increasing pore pressures with increasing distance from Room Q, Room C2, and Rooms L4 and 7, respectively. Pore-pressure estimates are available from more intervals (six) in borehole L4P51 than in any other hole, and show a clear trend of increasing pressure with distance from the excavation. (Only a lower bound on pore pressure is available from the seventh (D) interval in L4P51.)

Pore pressures tend to be most reduced directly above and below excavations, as shown by atmospheric-pressure (unsaturated) conditions encountered in two test intervals 0.2–0.4 room radii into the floor and in two test intervals 0.2–0.8 room radii into the roof of excavations. With one exception, the highest pore pressures shown in Fig. 8 at any normalized distance are from within pillars rather than directly above or below an excavation. Fig. 6, which presents data from around two rooms of similar size, clearly shows the increased depressurization above and below excavations compared to within pillars.

The highest pore pressures (>12 MPa) have all been measured in holes drilled outward into virgin rock from the extreme edges of the WIPP excavations. The highest pore pressure extrapolated for any test interval is 14.8 MPa for MB138 in QPP01 before the mining of Room Q. This value is equal to the estimated lithostatic pressure at the WIPP repository horizon (Wawersik and Stone, 1989), but we note that it is an extrapolated value only. The highest pressure actually observed in QPP01 was approximately 10.2 MPa (Domski et al., 1996). Pressures of 11.4 MPa (extrapolated to 12.9 MPa), 10.5 MPa (extrapolated to 12.4 MPa), and 11.8 MPa (extrapolated to 13.5 MPa) were observed in QPP03 (anhydrite b), QPP13 (MB139), and SCP01 (MB139) (Domski et al., 1996; Roberts et al., 1999). Thus, the highest observed (and extrapolated) pressures have been in anhydrite layers. In comparison, the highest pressures ever observed in halite are approximately 8.5 MPa (extrapolated to 9.6 MPa) in QPP12, 8.7 MPa in QPP22, and 8.8 MPa in QPP24 (Domski et al., 1996).

5.3. Discussion

Wawersik et al. (1997) interpret hydraulic-fracturing data to show that the stress state (and presumably the pore pressure) in MB140, 24–29 m (~six room radii) below the floor of Room C1, was clearly affected by the excavation. Wawersik and Stone (1989) reported that an isotropic stress field in halite at the WIPP, representative of conditions unaffected by the presence of excavations, was encountered only

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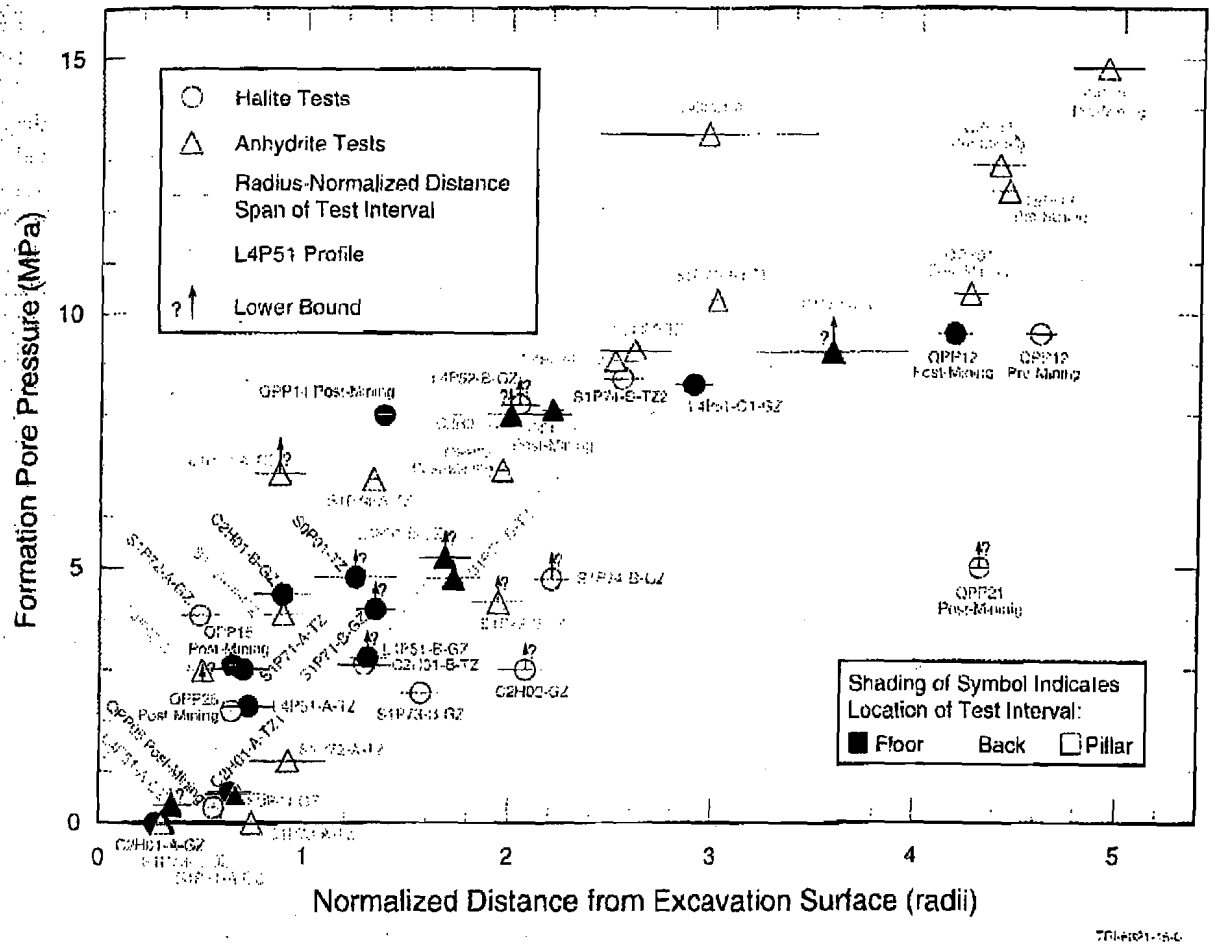


Fig. 8. Interpreted pore pressures versus radius-normalized distances from excavations.

at distances greater than 50 m laterally away from the excavations. Therefore, as no tests have been conducted more than 30 m from excavations, none of them may be outside the region of stress relief around the WIPP repository and we cannot be certain that any of the inferred hydraulic properties are representative of conditions in the far field.

Given this qualification, we nevertheless conclude that the permeability of anhydrite is generally higher than that of halite. The lowest anhydrite permeability inferred, 2×10^{-20} m^2, is nearly three orders of magnitude higher than the lowest halite permeability, 2×10^{-23} m^2. In general, anhydrite permeabilities are greater than 10^{-20} m^2 and halite permeabilities are generally less than that value. The consistency of the inferred anhydrite permeability values over a wide range of pore-pressure conditions suggests that far-field values would likely be similar. Appropriate values for the permeability of halite in the far field are less certain, but the data shown in Fig. 7 suggest that undisturbed impure halite may have a permeability on the order of 10^{-22}–10^{-21} m^2.

The pore pressure in a medium, such as halite, that undergoes creep might be expected to be equal to the lithostatic pressure because creep will continue until the deviatoric stress is zero. Pore pressures in anhydrite interbeds overlain and underlain by halite might also be expected to be equal to lithostatic pressure. A pore pressure approaching 15 MPa, corresponding to the estimated undisturbed lithostatic pressure at the WIPP horizon (Wawersik and Stone, 1989), has been never been observed in any test interval,

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although it has been extrapolated from pressure data from MB138 in QPP01 before the mining of Room Q (Domski et al., 1996). Even at the greatest distance from the WIPP excavations at which tests have been conducted, 24 m, observed or extrapolated halite pore pressures are less than 10 MPa (Fig. 8). Because halite has lower elastic moduli than anhydrite (Beauheim et al., 1991), we would expect halite to show more of a pore-pressure reduction in response to stress relief than anhydrite. Thus, observed pore pressures are consistent with all testing having been conducted within the region of stress relief around the WIPP excavations.

6. Evaluation of data and conceptual models

6.1. Far-field permeability

All six anhydrite layers tested have shown pressure responses indicative of permeability at all times and locations. Inasmuch as no anhydrite testing has been performed more than 24 m (or 4.6 room radii) from an excavation, this does not prove that all anhydrites are permeable in the far field. However, coupled with the observation of open bedding-plane fractures that are not thought to be related to the presence of the WIPP excavations (Borns, 1985), we believe that anhydrite is in fact permeable in the far field.

Eight halite intervals have been found that showed no pressure response indicative of permeability and pore pressure. These intervals comprised relatively pure halites at distances of 6–24 m (1.6–4.7 room radii) from the nearest excavations. At all other locations where halite has been tested, including 29 m (5.3 room radii) from the nearest excavation, pore pressure and permeability have been observed. In some cases, this may be a result of excavation-induced changes. In other cases, however, particularly the halite intervals 23 and 29 m (4.5 and 5.3 room radii) from excavations, we do not believe that the observed permeabilities could have been caused by excavation-induced changes. We believe that some halite intervals, particularly those with greater than a few percent impurities, naturally possess an interconnected pore network. All other things being equal, we would expect permeability to increase with increasing impurities in the halite, but this cannot be proved with the available data. Argillaceous halite may be the most permeable halite, because the clay may itself form an interconnected network.

Observations in boreholes drilled through the Salado from land surface show that, whether confined to the anhydrite layers or including some impure halite layers, some portion of the Salado must have far-field permeability. Drillstem tests performed in the Salado in seven boreholes showed little flow but clear pressure buildups (Mercer, 1987). Likewise, two boreholes registered positive pressure buildups at the wellhead indicative of brine levels above ground surface when the Salado was the only interval open to the wells (Sandia National Laboratories and D'Appolonia Consulting Engineers, 1982). These wells are unquestionably within the far field with respect to any excavations, and the pressure responses observed in these wells clearly demonstrate permeability.

6.2. Percolation model

The responses observed during the tests conducted of halite intervals in boreholes QPP02, QPP05, QPP11, QPP14, QPP15, and QPP21 before and after the mining of Room Q are consistent with Peach's (1991) theory about the development of percolation networks. In the undisturbed condition, the pores may have been too poorly connected to provide enough flow for a pressure-buildup response. After Room Q was mined and the halite had dilated to some degree, a better-connected pore network may have been formed through grain-boundary microfracturing, allowing permeability and pore pressure to be estimated. Under these conditions, the measured pore pressure must reflect local stress conditions in the rock because no real connection to a 'far-field' pore pressure exists. The orders-of-magnitude increase in permeability observed in the Small-Scale Mine-By experiment around the 96.5-cm hole is also consistent with dilation increasing the connectivity of the pore network.

No measurable permeability or pore pressure was observed during the testing of map unit 9 in borehole C2H03 (Beauheim et al., 1991) and of PH-4 in the guard zone of SCP01 (Beauheim et al., 1993). Both of these units are relatively pure halite. The tested intervals in C2H03 and SCP01 were 7.8–9.1 m (2.0–2.3 room radii) and 8.8–9.9 m (2.0–2.3 room radii), respectively, from the nearest excavations. Insuffi-

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cient dilation may have occurred at these locations to create an interconnected pore network above the percolation threshold.

Further evidence for the lack of interconnection among all halite porosity comes from geochemical observations. Krumhansl et al. (1991) discussed different brine chemistries associated with closely spaced (<1 m) weeps in the ribs of WIPP excavations. The pore diffusivity (D_p) required to prevent these chemistries from equilibrating over a distance of 1 m for 250 million years (7.9×10^{15} s) would be on the order of

$$D_p < (1\ \text{m} \times 1\ \text{m})/7.9 \times 10^{15}\ \text{s} = 1.3 \times 10^{-16}\ \text{m}^2/\text{s}$$

No pore diffusivity data are available for halite, but the lowest pore diffusivities reported by Ohlsson and Neretnieks (1995) for other low-porosity rocks (granite and gneiss) are several orders of magnitude higher than this value. Hence, halite pores must be extremely poorly connected. Consistent differences are also noted between the chemistries of brines from MB139, MB140, and map unit 0 (Roberts et al., 1999) that suggest that those units are not vertically interconnected. However, these conclusions about lack of connectivity in halite are based on average compositions. At the individual sample level, some percentage could be connected. Perhaps a percolation network exists that is somewhere below saturation, so some points in it are isolated. We do not know if the percolation network is also subcritical (below the percolation threshold). Nor do we know if this differs between/within layers and locations.

Peach (1991) also noted that the creation/enhancement of permeability during dilation could be simultaneously counteracted by the healing of fractures in halite. This implies that permeability is a dynamic property that cannot be measured at one time and then assumed to remain constant. The anomalous-appearing changes in pore pressure observed in boreholes QPP02, QPP04, and QPP14 after the mining of Room Q may reflect ongoing changes to the pore network.

6.3. Summary

The porosity of the rocks around the WIPP excavations appears to have increased, in some places significantly, due to dilation and fracturing at a variety of scales. Pore pressures have decreased in response to dilation, fracturing, and flow to the repository, resulting in partially saturated and/or two-phase conditions in some locations. Permeability has increased in some locations due to dilation, microfracturing, and shear and extensional fracturing, but decreased in other locations because of vertical stress concentration. Hence, the repository is surrounded by a partially brine-saturated zone with increased porosity and permeability which grades outward into a zone at full brine saturation with altered permeability and high hydraulic gradients, although the pressure is lower than in the far field. This zone of altered permeability may grade into a region where only pore pressure has been altered (lowered) from far-field conditions, which in turn grades outward into the undisturbed far-field formation. The extent and properties of these zones are continuing to change as the stress field around the repository evolves.

On the time scale of the operational period of WIPP (decades), the far field lacks the capacity to fill all of the newly created porosity in and around the repository, much less pressurize it to near lithostatic pressure. After WIPP is closed, far-field flow toward the repository will continue, but the overall 'healing' of the formation around the repository (closure) and compaction of the crushed-salt backfill will act to reduce both the hydraulic gradient and the porosity present near the waste. Thus, the amount of brine that ever comes into contact with waste will be controlled by the relative rates at which brine flow and repository closure occur.

7. Implications for modeling

The existence/occurrence of excavation-induced permeability and pressure changes, pressure-dependent permeability, and non-radial flow dimensions in the Salado has implications with regard to modeling of flow and transport. If hydraulic properties are dependent on current and past stress states, permeability values derived from tests conducted at locations under particular stress regimes cannot be assigned throughout a modeling domain with a variable stress regime. A rigorous model should include a coupling between hydraulic properties and the stress field, with

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a full recognition of the time-dependence of conditions and properties.

Finite-difference and finite-element models constructed with homogeneous layers have implicit flow dimensions of 2 if the permeable layers are completely confined or some value between 2 and 3 if different layers have different properties or properties are anisotropic. Incorporating heterogeneity in permeability within layers can alter the flow dimension. We now recognize that no inferred value of permeability can be separated from its associated flow dimension. If a permeability estimated assuming a subradial flow dimension is used as input to a homogeneous flow model, flow will be overestimated. Flow may, likewise, be underestimated if a permeability estimated assuming a greater-than-radial flow dimension is used in a model having an implicit dimension of 2.

Each of the layers of the Salado represented in the modeling for the WIPP Compliance Certification Application (US Department of Energy, 1996) was treated as homogeneous. As a result, the CCA modeling calculated a larger brine flux toward and away from the WIPP repository than would have been calculated had conditions giving the subradial flow dimensions observed in most of the tests been implemented. However, the same CCA modeling would, for a given flux, underestimate the distance to which brine would flow away from the repository because it would assume that the brine was spread evenly through the entire volume of rock instead of being channeled within some smaller percentage of the volume. Based on the test results presented in Roberts et al. (1999), the Salado might better be modeled as a heterogeneous medium with non-radial flow dimensions.

All of the Salado permeability tests were conducted under conditions of induced high hydraulic gradients. Success in applying a Darcy-flow model to the interpretation of these tests does not necessarily imply that the model would provide a valid description of flow through the Salado under natural low-gradient conditions, as discussed by Beauheim et al. (1993). The available data suggest that a Darcy-flow model should adequately describe flow in the near-field around the WIPP repository so long as gradients are high, but flow may be overestimated after the repository pressurizes and gradients decrease.

8. Conclusions

Our conceptual model for far-field Salado hydrology involves permeability in anhydrite layers and at least some impure halite layers. Pure halite layers and some impure halite layers may not possess an interconnected pore network adequate to provide permeability. Pore pressures are probably very close to lithostatic pressure. In the near field (DRZ) around an excavation, dilation, creep, and shear have created and/or enhanced permeability and decreased pore pressure. Very close (<1 m?) to the excavations, these changes have resulted in partially saturated conditions. Whether flow occurs in the far field under natural gradients or only after some threshold gradient is reached is unknown. If far-field flow does occur, mean pore velocities are probably on the order of a meter per hundreds of thousands to tens of millions of years.

Pressure-pulse, constant-pressure flow, and pressure-recovery tests have been performed in anhydrite and halite intervals to evaluate the hydraulic properties controlling brine flow through the Salado. Permeabilities ranging from approximately 2×10^{-23}–3×10^{-16} m^2 have been interpreted from tests conducted on 30 stratigraphic intervals within 23 m of the WIPP underground excavations. Typical average permeability values for anhydrite range from approximately 10^{-20}–10^{-18} m^2, while those of halite are less than 10^{-20} m^2. In the far field, halite permeabilities are probably less than 10^{-21} m^2, except possibly in highly argillaceous halites. Pore pressures in 66 stratigraphic intervals range from atmospheric to 14.8 MPa.

Permeabilities of some tested intervals have been found to be dependent on the pressures at which the tests were conducted, which is interpreted as the result of fracture apertures changing in response to changes in effective stress. Flow dimensions inferred from most test responses are subradial, which we believe reflects channeling of flow through fracture networks, or portions of fractures, that occupy a diminishing proportion of the radially available space, or through percolation networks that are not saturated (fully

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interconnected). This is probably related to the directional nature of the permeability created or enhanced by excavation effects. Other test responses indicate flow dimensions between radial and spherical, which may reflect propagation of pressure transients above or below the plane of the test interval or into regions of increased permeability (e.g. closer to an excavation). The variable stress and pore-pressure fields around the WIPP excavations probably contribute to the observed non-radial flow dimensions.

Inferred values of permeability cannot be separated from their associated flow dimensions. Therefore, numerical models of flow and transport should include heterogeneity that is structured to provide the same flow dimensions as are observed in hydraulic tests. Modeling of the Salado Formation around the WIPP repository should also include coupling between hydraulic properties and the evolving stress field because hydraulic properties change as the stress field changes.

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Keep It in the Ground

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Introduction

Thanks to the historic Paris climate agreement, the world now knows what it will take to stay within our global carbon budget. If the world is serious about tackling climate change, we need to fight for fewer oil wells and coal mines. This report explains where these campaign fights need to occur.

The global carbon budget describes how much carbon can be emitted into the atmosphere before warming surpasses 2˚C—the limit scientists and policymakers have established as the boundary for catastrophic climate change.

The adoption of the Paris Agreement by nearly 200 countries in December commits countries to this budget and requires that they take steps to reduce emissions.

At this critical juncture following the Paris Agreement, this report builds upon Point of No Return, a groundbreaking 2013 investigation commissioned by Greenpeace International and undertaken by Ecofys. Using a similar approach, this updated report reflects that a number of carbon threats from the 2013 report have abated, and it assesses emerging projects and trends that put the climate and planet at risk.

Keep It In The Ground examines the coal, oil and natural gas deposits around the world that pose the greatest risk to the climate if burned for fuel. Including an overview of efforts by fossil fuel companies and their political allies to develop these resources, the report provides a roadmap for the international climate movement in the post-Paris Agreement world.

Carbon Threats

Potential Emissions between 2013-2050 (in Gt CO2e)




Russia
34.4
Turkmenistan,
Kazakhstan,
Azerbijan
10.0
China
45.3
Iraq
21.1
Saudi Arabia
115.2
India
57.0
Indonesia
15.4
South Africa
12.0
Australia
36.0

The Carbon Budget

According to the Intergovernmental Panel on Climate Change (IPCC), the cumulative carbon budget between 2011 and 2050 is around 870-1,240 Gt CO2, which gives a better-than-even chance of avoiding warming above 2˚C and factors in other greenhouse gases.

For an 80 percent chance of limiting warming to 2˚C or less, Carbon Tracker's Unburnable Carbon report finds a carbon budget of 886 Gt CO2 for 2000 to 2050; we used up a third of that budget from 2000 to 2011 alone. To reach a four-in-five chance of preventing catastrophe, we have approximately 565 Gt CO2 left in our carbon budget until 2050. To limit warming to 1.5˚C or below—an ambitious goal stated in the Paris Agreement—emissions would need to be limited in accordance with an even stricter budget.

Carbon Tracker estimates current known global fossil fuel reserves at 2795 Gt CO2, while other research suggests the figure is closer to 2900 Gt CO2.[1] This means that if the world's proven reserves are developed before 2050, we will miss even the high-end estimated budget for a 50 percent chance of limiting warming to 2˚C—three times over. The calculations for the low-end estimate indicate the need for even trimmer carbon budgets, which would provide a better chance of avoiding catastrophe.

Unless these reserves stay underground or beneath the ocean, any chance of limiting warming to 2°C or less will be lost.

A recent study published in Nature recommends that a third of oil reserves, half of gas reserves, and more than 80 percent of current coal reserves worldwide need to be left alone and remain unused in order to meet the 2°C target.

The authors stress that, in order to stave off catastrophic climate change, the overwhelming majority of the large coal reserves in China, Russia and the United States as well as more than 260 billion barrels of oil reserves and 60 percent of gas reserves in the Middle East must all remain unused. Finally, the study finds that Arctic resources should be off-limits to development and that the exploration and usage of unconventional oil, like the high-carbon Canadian tar sands, undermines any efforts to limit climate change.

There is also growing international support for a moratorium on all new coal mines, led by President Anote Tong from Kiribati. The call has already been backed by several other small island nations. Recently, China also announced a three-year moratorium on all new coal mines.

In 2014, carbon dioxide emissions reached 35.9 billion tons, including a 2.9 percent increase in the United States over 2014, reversing a decline of the last four years, according to projections released in December 2015 by the Global Carbon Project.

The International Energy Agency announced in 2014 that their preliminary data showed that growth in carbon emissions from the energy sector had stalled. The agency also pointed out that this marked "the first time in 40 years in which there was a halt of reduction in emissions of the greenhouse gas that was not tied to an economic downturn." The Global Carbon Project's 2015 report also projected that carbon emissions declined by 0.6 percent in 2015.

If carried to completion, these projects would emit a projected 300 Gt of CO2 over their lifetimes—equal to eight times current global emissions—which would destroy vital ecosystems, and threaten the security and prosperity of humankind.[2]

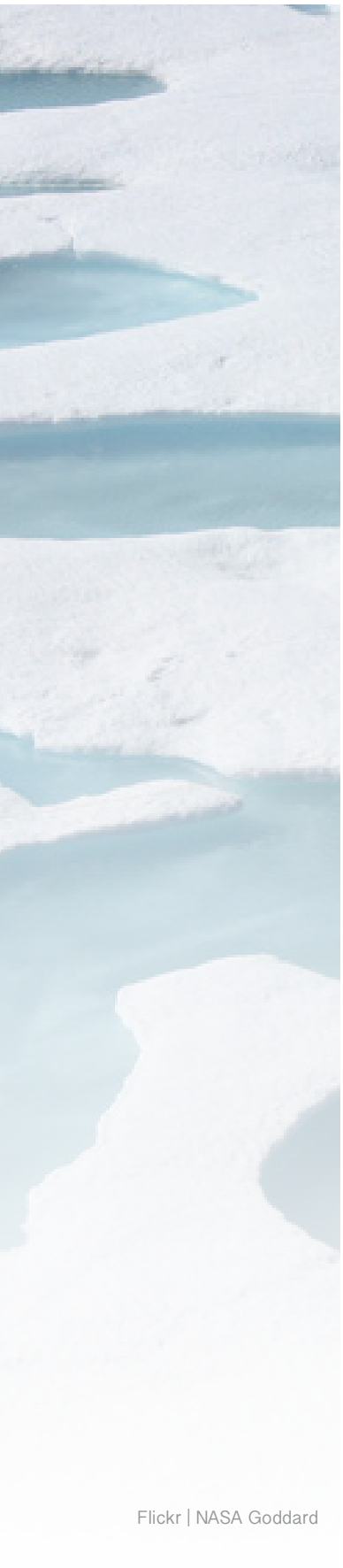
The reserves of coal, oil and natural gas outlined in this report contain enough carbon to rocket the planet far beyond the 2˚C limit. Warming from fossil fuels puts other carbon sinks at risk. As permafrost melts and peat bogs dry, they emit enormous quantities of carbon dioxide, furthering a chain reaction where the release of carbon results in a warmer world, which in turn releases more carbon.

We are already experiencing the dire consequences of climate change in the form of extreme weather events, including pervasive heat waves, droughts, floods, intense and destructive hurricanes and wildfires, and even monster snowstorms. Beating 2014's record, 2015 has earned the distinction of having been the hottest year since record keeping began. Experts expect 2016 to be warmer still.

The consequences of the mounting carbon emissions in our atmosphere are increasingly costly, and impossible to ignore. As part of an ongoing global effort to "Keep It In The Ground," the climate movement intends to confront the threats described in this report, as well as others at the local, state, and national level.



The Arctic



Global warming has contributed to the rapid melt of Arctic ice and exposed new avenues for the development of fossil fuel reserves. If extracted and used, these fuels will accelerate global warming and the melting of Arctic ice.

In anticipation of the newly exposed fuel sources, oil companies have started a rush on the Arctic, which is estimated to contain 90 billion barrels of oil and 1,670 trillion cubic feet of natural gas.[3]

According to Ecofys, oil production in the Arctic could grow to 3 million barrels per day in 2030. If the existing oil reserves are fully tapped, the drilling could add a total of 15.8 gigatons of carbon dioxide equivalent (Gt CO2-eq) between 2013 and 2050.[4]

The race to the Arctic, however, has become an uphill battle. Companies now face numerous legal challenges from environmental groups and obstacles within the federal permitting process.

Questions also remain on whether Arctic drilling is technically and economically viable. Some companies, including Chevron, have abandoned their near-term drilling plans as a result of the international slide in oil prices and a tougher regulatory climate.

Royal Dutch Shell, for example, announced that it would abandon its exploratory drilling plans in the Beaufort and Chukchi Seas off the Alaska coast, saying it found insufficient oil and gas to justify continuing the costly development process. After years of vying for drilling rights in the face of opposition by concerned citizens and regulatory reviews, Shell announced its reversal just months after President Obama's decision to allow drilling to proceed. A victory for environmentalists, it was the latest in a series of setbacks for the company. Shell has a history of errors and accidents in its Arctic fuel exploration, including the December 2012 grounding of a drilling vessel in stormy seas.

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"Shell's plans to drill in the Arctic, one of the world's most pristine and extreme regions – which was only made accessible by melting ice cover due to climate change – was not only a financial and environmental gamble, but it become politically toxic as people across the world joined together to raise the alarm.

You might have thought that a retreat from the Arctic by one of the biggest most established companies in the world would be a clear signal to the broader industry that Arctic oil is not worth the risk. However there are still both national and international oil companies with license blocks at the Arctic frontiers, and the struggle to save the Arctic seems far from over."

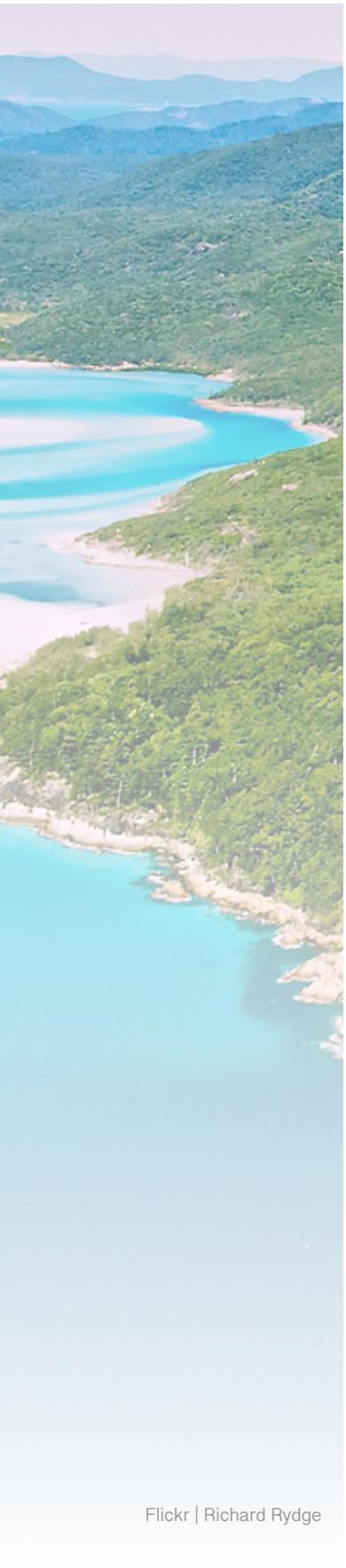
- Sophie Allain,
Arctic Campaigner, Greenpeace International

In more good news for opponents of Arctic drilling, in October 2015 the Department of the Interior canceled two Arctic offshore lease sales scheduled for 2012-2017. Under the current five-year program offshore oil and gas-leasing program, Chukchi Sea Lease Sale 237 was scheduled for 2016 and the Beaufort Sea Lease Sale 242 for the first half of 2017.

The Bureau of Safety and Environmental Enforcement (BSEE) also denied requests from Shell and Statoil for lease suspensions, which would have allowed the companies to extend their leases beyond 10 years. The Beaufort lease is scheduled to expire in 2017; Chukchi in 2020.

Recent research recommends against any drilling in the Arctic. In January 2015, the Obama administration proposed new protections for Alaska's Arctic National Wildlife Refuge, recommending that more than 12 million acres, including the oil-rich coastal plain, be designated as wilderness—the highest level of protection for public lands. This would halt oil exploration in the coastal plain, but this proposal will likely face heavy challenges from the current Republican-led Congress.

Australia



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Coal mining expansion in Australia could add a total of 36 Gt of CO2 equivalent to the atmosphere between 2013 and 2050. There are more than 60 coal mining projects in New South Wales and Queensland, with a targeted coal output of approximately 450 to 500 million metric tons per year, excluding projects that have been abandoned or shelved.[5]

This is a significant reduction from the outlook in 2012, when the World Resources Institute Global Coal Risk Assessment identified 800 to 900 million metric tons of planned production capacity.

However, the planned mining expansion in Australia represents an enormous threat to the planet, with the targeted additional output far exceeding what the International Energy Agency (IEA) sees consistent with a catastrophic 5 to 6˚C warming scenario.

Australian coal export volumes experienced double-digit growth in 2013 and grew strongly again in 2014 to roughly 375 million metric tons, a 24 percent increase from 2011 to 2012.[6] The pace of growth slowed from 2014 to 2015,with export volumes increasing by 4.8 percent (398 million metric tons), according to the Office of the Chief Economist.[7]

As the price of coal has plummeted, Australian producers are making up what they lost in value by working their employees harder. The tonnage of coal produced per employee in Queensland rose 18 percent in 2014.[8] Most of this extra volume came from existing mines, but some large new projects, like the Maules Creek coal mine in NSW's Gunnedah Basin and Caval Ridge in Queensland's Bowen Basin have started production.

"That is very disheartening…the slump in Asia has not led to a fall in volumes expected from Oz (Australia) – just the opposite. The lower value of the Oz dollar has meant our coal producers could ramp up production and grab greater market share, even while they are laying off workers in the thousands. Australia is, in effect, making itself more and more vulnerable to the volatile global coal market at a time when we should be putting in place programs and measures to diversify and shield people in our coal producing regions from dramatic changes to coal's prospects as a commodity."

-Georgina Woods,
Australian community-based energy and resources analyst

In 2012, according to the Bureau of Resource and Energy Economics (BREE), there were 97 new coal mining projects, including expansions and new mines, proposed in New South Wales and Queensland.[9]

By December 2015, of those projects:

- 34 were approved, but only five proceeded to construction
- 12 were withdrawn or shelved
- One was rejected by a determining authority
- One was stymied by impossible conditions imposed by a court
- Five are currently under legal challenge

Many more have been delayed beyond their expected start-up time. BREE predicted that five new projects would begin producing in 2013, but only three have done so. Out of the 16 that were expected to begin producing in 2014, only half of them did.

As of 2015, there are roughly 65 coal projects that still pose a threat to land, water and communities in New South Wales and Queensland, and to the global climate. Some of these projects already have been approved and present an immediate threat, while others have been delayed for years by the efforts of communities fighting them.[10]

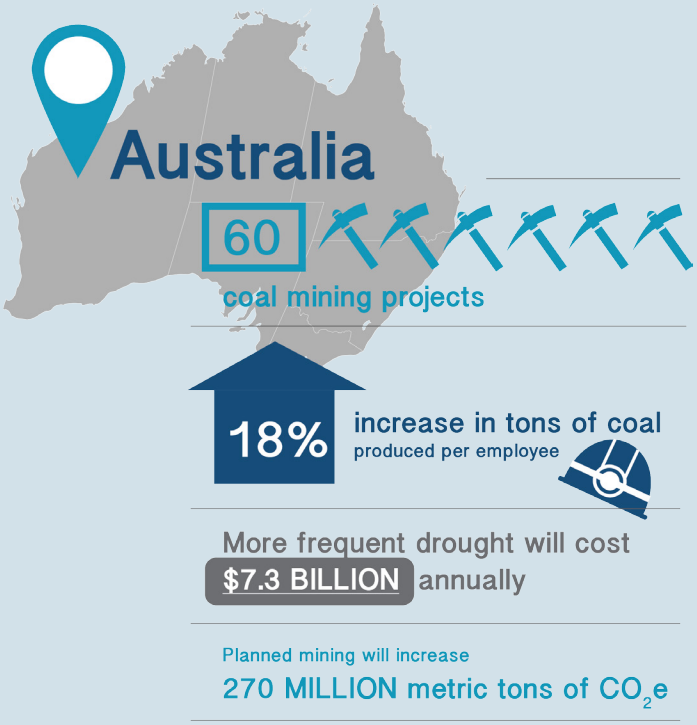
Most of these projects are in the existing and heavily exploited coal regions of southern Sydney, the Hunter Valley and Queensland's Bowen Basin. But six international coal companies are planning nine new mines in central Queensland's Galilee Basin. Altogether, the mines proposed in this new region would create 700 million metric tons of carbon dioxide every year, markedly increasing Australia's greenhouse gas emissions.

Five of the nine proposals received approval from the Queensland and Australian Governments, but the companies have yet to begin construction. In total, 11 international banks have refused to fund Galilee Basin projects.

While banks back away from fossil fuel investments, the Australian government continues to heavily subsidize fossil fuel projects. According to Reneweconomy, Australia subsidizes fossil fuel production with $3.77 billion a year, and also funds the industry with a further $262 million a year in public finance.

Australia's environmental ministry approved the Carmichael mine, country's largest mining project in October 2015, overturning a federal court's decision to halt the project just two years prior.

Current predictions suggest that coal extracted from the Carmichael mine would produce 128.4 million metric tons of carbon dioxide per year over the mine's lifetime.



That's almost a quarter of Australia's current annual emissions, which stood at 546.7 million metric tons of CO2 equivalent in 2014.

When added to the roughly 900 million metric tons of CO2 equivalent created by burning the 375 million metric tons of coal Australia is already exporting, the expanded coal mining would increase the greenhouse gas contribution of Australia's coal exports to 1.6Gt a year[11] over the next five years. Australia's Office of the Chief Economist expects total Australian coal exports to rise to 433 million metric tons by 2020, taking the greenhouse impact of Australian coal exports to more than a gigatonne per annum.[12]

If it allows mining in in the Galilee Basin, Australia faces the prospect of losing an iconic and irreplaceable natural and economic asset. The port and shipping activity required to export the additional coal would cause serious damage the Great Barrier Reef, which is already under severe stress from climate change. Indeed, the Great Barrier Reef Outlook Report 2014 identified climate change as the greatest threat facing the region, declaring that its deleterious effects already are at work.

But the Reef is not all Australia stands to lose. If these fossil fuels are not kept in the ground, Australia's already evident climate impacts – including powerful storms, heat waves and bushfires – will worsen.

Australia is already experiencing more frequent and intense heat waves. The Climate Council has warned that deaths from heat waves are projected to double over the next 40 years in Australian cities. From 2020 onwards, the predicted increase in drought frequency "is estimated to cost $7.3 billion annually, reducing GDP by 1 percent per year."[13]

Canada



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Between 2013 and 2050, Canada could add a total of 17 Gt CO2 equivalent to the atmosphere.[14]

By 2020, Canada's tar sands projects are expected to add 420 million metric tons of carbon dioxide to the atmosphere each year, a rate equivalent to the entire annual emissions of Saudi Arabia.[15]

Without the implementation of strong policies to protect the climate and the local environment, production of oil from the tar sands in Alberta is forecast to triple from 1.5 to 4.5 million barrels a day by 2035, adding 706 million metric tons of carbon dioxide a year to worldwide emissions.

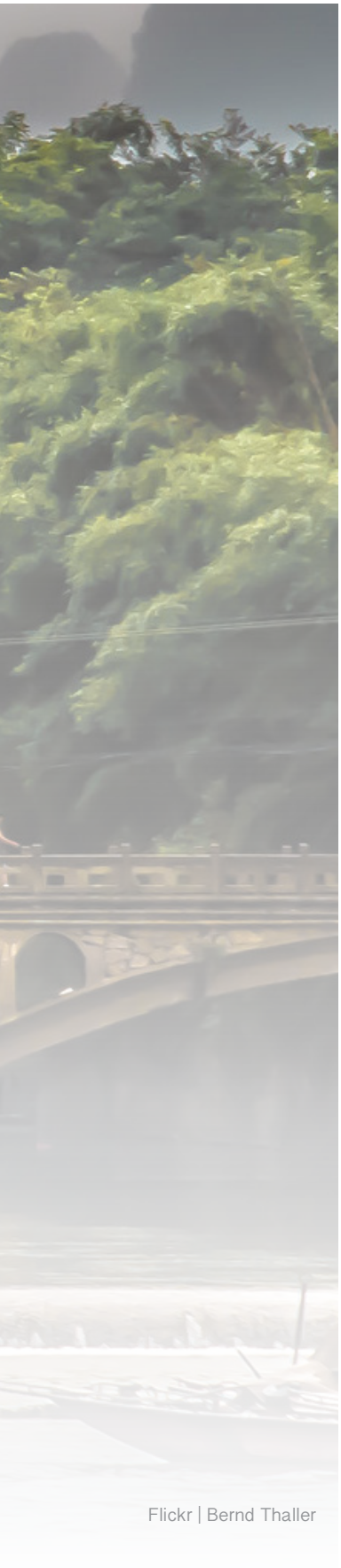
> *"Tar sands oil is the dirtiest oil on the planet. It requires turning a rock into a liquid, and requires a lot of energy, since it is very hard to get carbon out of the ground. Given climate change, we don't have a lot of spare carbon. It would be a major contributor to climate change, and it definitely has to stay underground."*
>
> – Jake Schmidt, international program director, Natural Resources Defense Council

In a highly significant decision—and a huge victory for environmentalists, indigenous peoples, ranchers, farmers, and more—President Obama recently rejected the Keystone XL pipeline, a proposed tar sands pipeline that would have connected Alberta with Gulf Coast refineries and carried 800,000 barrels per day of tar sands oil across the United States for refining, and export.

During the seven-year Keystone fight, the pipeline became a symbol of the highly contentious political debate over climate change. According to 350.org, the Keystone XL pipeline would have been "the fuse to the largest carbon bomb on the planet."[16] An NRDC report concluded that the Keystone pipeline would have contributed 18.7 million to 24.3 million metric tons of CO2 equivalent per year.

The Obama administration was bitterly castigated by Republican lawmakers and the oil industry for rejection of the controversial pipeline, but U.S. Secretary of State John Kerry declared that the United States "cannot ask other nations to make tough choices to address climate change if we are not willing to make them ourselves."

China



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China is the world's largest CO2 polluter, and studies suggest that China will soon surpass the United States as the largest contributor to climate change since 1990, even though its emissions fell for the first time in 2014.

The World Resources Institute estimates that China's cumulative emissions will reach 151 billion metric tons by the end of 2016. Yet, changing energy and economic policies will enable China to peak its coal use before 2020.

China's coal production and consumption fell in 2014 for the first time this century. Recent statistics from China indicated that the country has been burning 17 percent more coal annually than previously reported, but its calculated carbon emissions remain the same.

In September 2015, President Obama and Chinese President Xi Jinping signed a landmark climate change agreement in which both countries pledged to limit their carbon emissions.

In the deal, China announced it would use a cap-and-trade system to peak CO2 emissions by 2030 or earlier, and to increase the non-fossil fuel share of all of its energy to approximately 20 percent by 2030. These commitments came on top of China's ambitious 2020 targets to limit total energy consumption, increase its share of non-fossil energy, and improve air quality by requiring prosperous eastern provinces to peak emissions and decline coal consumption by 2017.

China is expected to dramatically reduce its targets for coal-to-gas, coal-to-oil and other coal chemical conversion projects in its next five-year plan, eliminating the last remaining source of industrial coal consumption growth. In March 2015 Beijing announced that it will close its last major coal plant in 2016.

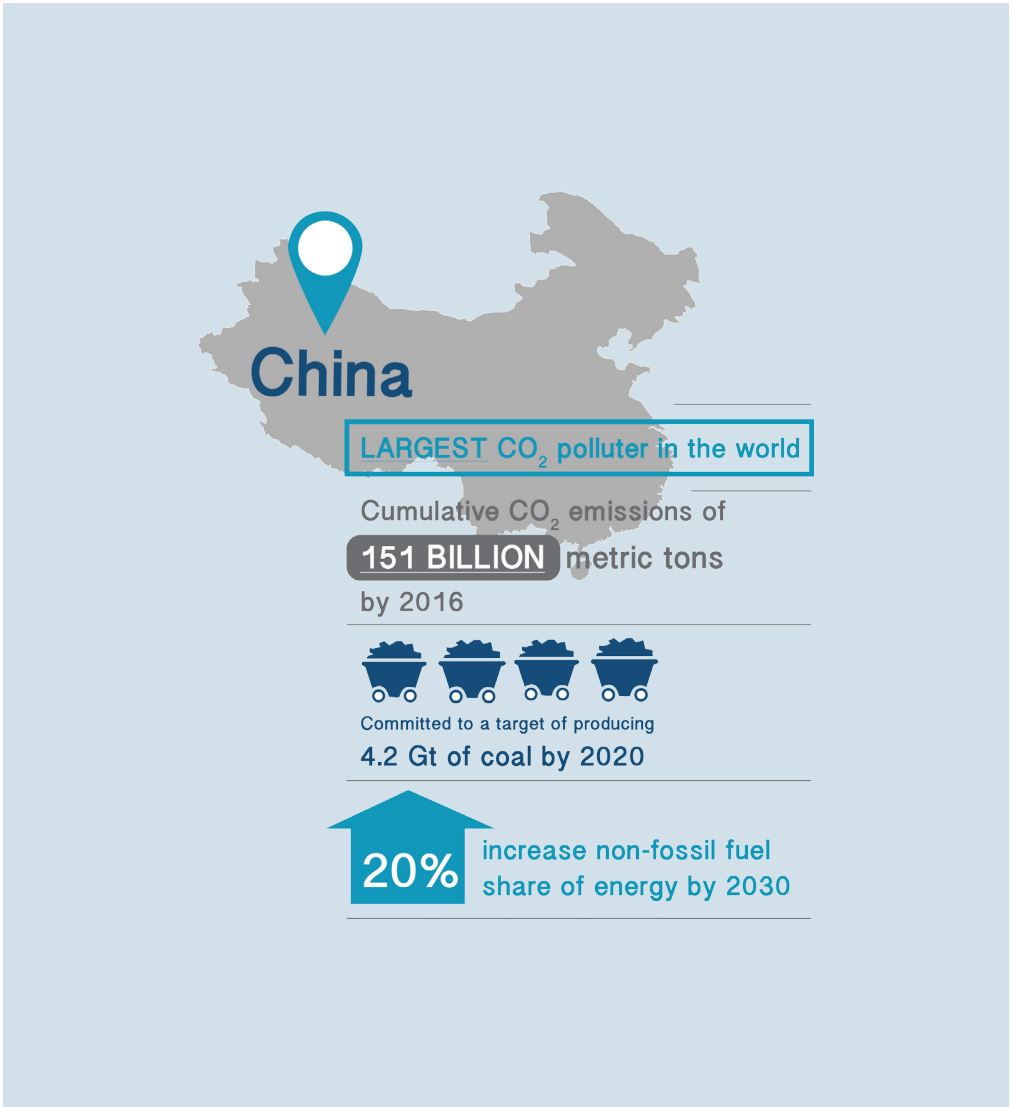
As a result of the lowered estimates for expected coal demand in 2020, the CO2 threat from China's western coal bases has shrunk significantly from the 2013 estimate of 45.3 Gt of CO2 equivalent to the atmosphere between 2013 and 2050.[17]

Nevertheless, the Chinese State Council is still committed to developing 14 coal bases, with the target of producing 95 percent of national total coal output by 2020.

The official target for coal consumption in 2020 is 4.2 Gt, which allows for a substantial increase of 600 million metric tons. Assuming coal output is equal to consumption, the coal bases would produce 4 billion metric tons—a significant threat.

"It is increasingly clear that the planned coal expansion in China flies in the face of the clean air and economic rebalancing agendas."

- Lauri Myllyvirta, senior global campaigner on coal, Greenpeace International





The United States



Flickr | Giuseppe Milo

Climate and energy policy in the United States has progressed substantially in recent years, with dramatic growth in renewable energy production and planned domestic actions to reduce greenhouse gases established under the Clean Power Plan. The U.S. has increasingly turned away from coal towards renewable energy. Production of shale gas has ramped up during this transition period, but it's key that the country turns away from gas and invests in renewable energy to meet its climate pledge.

In 2015 several Democratic senators introduced legislation that would prohibit new leases on coal, gas, oil and tar sands extraction on federal lands in the United States. The bill, sponsored by Democratic Senators Jeff Merkley of Oregon and Bernie Sanders of Vermont, would also ban offshore drilling in the Arctic and Atlantic Ocean and forbid the renewal of leases that have not yet produced fossil fuels.

In the face of tightening restrictions on coal use, the oil and gas industry has increased production of cheap and plentiful oil and shale gas. The International Energy Agency forecasts an increase of 249 billion cubic meters from 2012 to 2035 in U.S. shale gas output.

The boom in hydraulic fracturing ("fracking")—the process of drilling and injecting fluid into the ground at a high pressure to fracture shale rocks and release the natural gas inside—has given rise to more than 110 liquefied natural gas (LNG) export facilities and terminals in the United States, with more awaiting regulatory approval.

These terminals perform a variety of functions, including: transforming liquefied gas back to a gaseous state; exporting natural gas; providing a natural gas supply to the interstate pipeline system or local distribution companies; or storing natural gas for periods of peak demand.[18]

"Instead of blindly allowing destructive fracking to continue in our communities, we should extend statewide fracking bans, like the one in New York, and moratoriums, like the one in Maryland, that will keep dirty, climate-polluting fossil fuels like fracked gas in the ground and invest in truly clean, renewable sources of energy that don't come with the threat of poisoned drinking water and climate disaster."

- Michael Brune, Executive Director,
Sierra Club

A single LNG facility is not in and of itself a threat to the carbon budget. But collectively, these facilities play an important role by driving the drilling and combusting of fossil fuels and enabling the unconventional hydrocarbon boom in the United States, with major implications for the nation's carbon footprint.

Between 2013 and 2050, the United States is expected to emit a cumulative total of 34 Gt of CO2 equivalent emissions from shale gas and tight oil expansion.[19]

LNG Case Study: Cove Point, MD[20]

Dominion's Cove Point facility would be the first LNG export terminal on the East Coast. Its opponents, chief among them the Chesapeake Climate Action Network, argue that it would increase the demand for more fracking in the region and require an expanding network of new fossil fuel infrastructure. A rise in fracking and infrastructure-related emissions could have devastating effects on the local environment, as well as increase the region's contributions to climate change.

The Federal Energy Regulatory Commission has approved permits for Dominion's Cove Point project, but legal challenges and grassroots resistance continue.

The project would cost upwards of $3.8 billion dollars, require the construction of an energy-intensive plant to liquefy and cool the gas, draw a surge of tanker traffic into the Chesapeake Bay, and facilitate the export of more than 1 billion cubic feet of fracked natural gas per day.

The new liquefaction facility that Dominion would have to build on-site to process gas for export would emit more heat-trapping carbon dioxide than all but three of Maryland's existing coal plants. In all, given the energy-intensive process of extracting, transporting and processing gas for export, Cove Point would produce more greenhouse gas emissions than any other single source of climate pollution in Maryland. This LNG terminal is a prime example of a state-level carbon bomb.

Moreover, the process of exporting gas from Cove Point would require huge, 1,000-foot long tankers to carry volatile, potentially explosive liquid

fuel in an area important for its seafood and tourism. Harmful emissions from those tankers would worsen local air quality, and the ships would dump billions of gallons of dirty ballast wastewater into the Chesapeake Bay each year.

Finally, the project also would need new pipelines throughout the Marcellus shale states to move gas from new drilling wells to the export terminal—pipelines that could leak and break, causing explosions and fires.

"Natural gas is methane, LNG is 99 percent methane. It is, pound for pound, 86 times more potent than CO2 over 20 years, and 30 times as potent over 100 years. The negative environmental and climate change impacts that could be triggered by Cove Point are sadly not unique to that facility, but could in fact become the norm for LNG exports if that industry is allowed to expand in this country without serious regulations. Cove Point is the poster child for the environmental controversies around LNG."

– James McGarry, Maryland & D.C. policy director, the Chesapeake Climate Action Network

India



Flickr | sandeepachetan

India's rapidly growing energy needs and reliance on coal threatens to quickly eat away at the global carbon budget.

India's coal-fired power plant capacity surged from 90 gigawatts in 2010 to 165 gigawatts in 2014, a rate equivalent to adding a large coal-fired power plant every two weeks. This pace is set to continue for the next few years, with approximately 80 gigawatts of capacity under construction. India's planned coal expansion could add a total of 57 Gt of CO2- equivalent emissions between 2013 and 2050.[21]

But, several factors are darkening the outlook for Indian coal plants. Coal India's inability to meet production targets led to a shortage of domestic coal. Subsidies for expensive imported coal, successful citizen opposition to coal production, uncertainty in the international coal markets, competition from increasingly cheap renewables, plus a major political scandal in which the Indian government sold national coal deposits for much less than their market value have all led banks and other financiers to hesitate before investing in coal-fired power plant projects, causing a slowdown in construction.

Beyond the domestic factors, the Paris Agreement is a dominant force in the shift towards renewable energy. India, the third biggest emitter of greenhouse gases in the world, announced in its INDC a plan to obtain 40 percent of its electricity from renewable and other clean energy sources by 2030. France, the United Arab Emirates, and the United States, among others, have pledged to contribute funding or expertise to facilitate India's renewable energy development. Prime Minister Narendra Modi, an enthusiastic backer of solar power, advised the country's oldest coal-fired plants to bundle electricity from solar farms for sale to the grid.

"India's commitment to climate action puts the nation on a much more sustainable path while investing in a massive addition to the world's thriving clean energy economy. The planet's four largest emitters of carbon pollution have now shown that meaningful climate action is not only achievable, but that it's already happening."

- Michael Brune, Executive Director, Sierra Club

While the Indian government has set groundbreaking targets for renewable energy, it still supports coal projects. The Modi administration frequently cites the 237 million Indians without access to electricity as the reason for their continued dependence on accessible dirty fuels. However, in January 2016, solar tariffs dropped to a new low of INR 4.34 / kWh per hour, indicating that solar power is quickly becoming cheaper than new coal.

There are over 200 gigawatts worth of new coal-fired power plant projects in various proposal, planning and permitting stages in India. To bridge the gap between the domestic coal supply and the enormous demand for domestic coal that would be created by these projects, the Modi administration set a goal of increasing coal production from Coal India Limited upto one billion tons a year by 2019, and with another 500 MT expected from other private or captive mining sources. They also pledged to "clear hurdles" to new mines, including environmental and social safeguards.

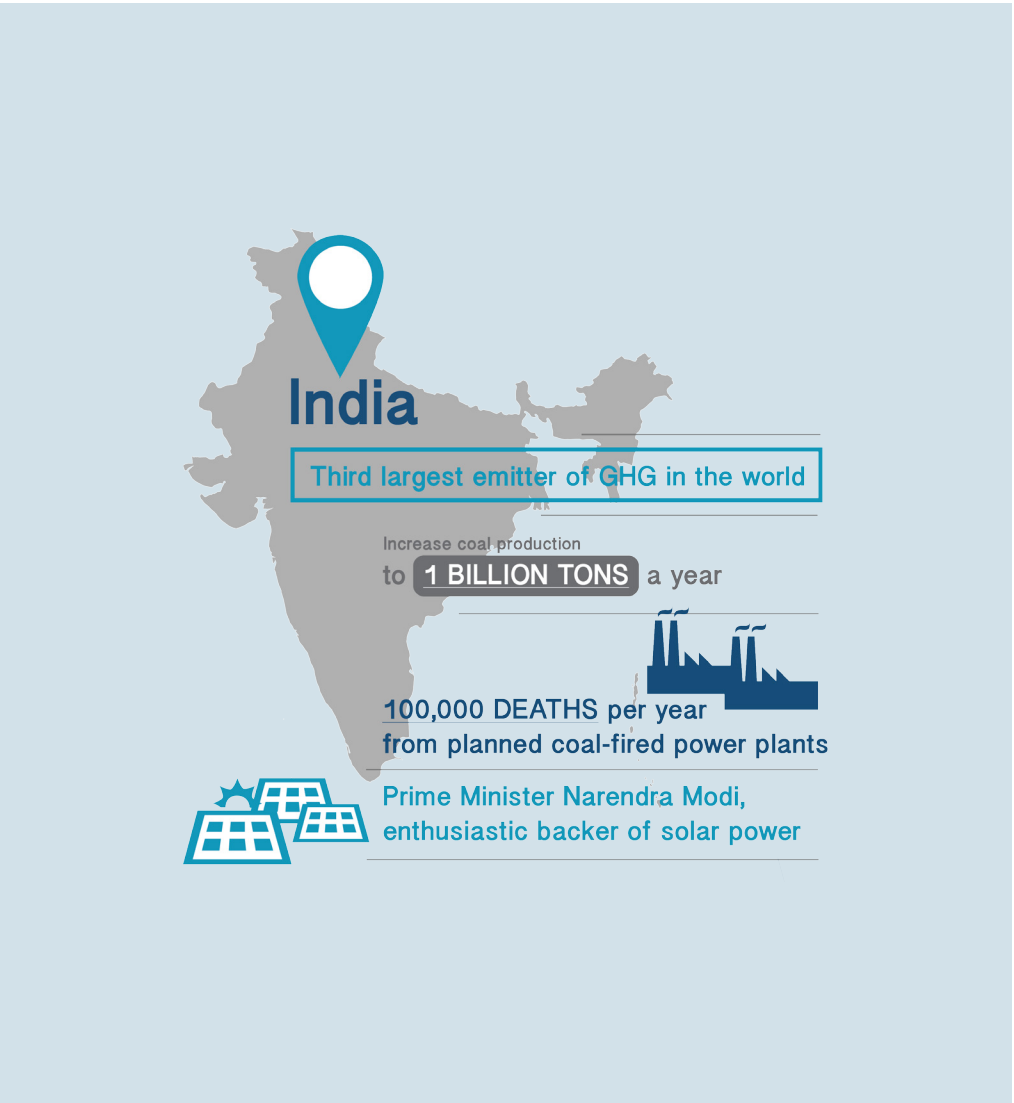
To achieve this target, coal production would have to grow by 9 percent annually. By comparison, from 2009 to 2014, coal mining increased by only 6 percent. India also missed its target to ramp up coal output to 680 million tons by the end of the 11th five-year plan (2007-12), as production touched only 540 million tons in 2011/12.[22]

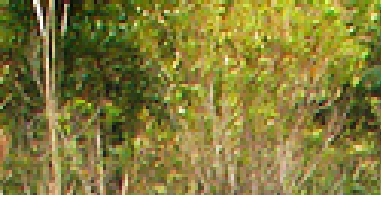
India's domestic supply target reflects the government's intention to aggressively develop India's coal resources, and therefore presents a major threat to the 2˚C limit.

It also presents a major threat to public health. According to a recent report, air pollution from India's existing coal-fired power plants cause an estimated 100,000 deaths per year.[23] The report also projects that the country's total premature mortality resulting from emissions from coal-fired thermal power plants would grow by two to three times, reaching 186,500 to 229,500 annually in 2030. In the same period, the number of asthma attacks associated with coal-fired power plant emissions is expected to increase to 42.7 million cases per year.

The projects would add approximately 2,100 million tons of CO2 per year into the atmosphere, almost equal to India's current total CO2 emissions, or 5 percent of global emissions from fossil fuel burning.[24] At the current rate of power plant additions, these plants could be commissioned in fewer than 20 years. The plan to increase Coal India's coal output could add 700 Mt of CO2 in just five years, more than the total emissions of Indonesia or Canada.

India's current per capita CO2 emissions are low, at only 1.7 tons per person, compared to China, at 6.9 tons and the United States at 17 tons.[25] However, as the European Union (EU) is committed to cutting its domestic emissions by 80 percent from 1990 levels by 2050, and the coal-fired power plant expansion could double India's per capita emissions in two decades, this development path could see India's per capita CO2 emissions overtake the EU in 20 years or less.





Brazil



Flickr | Diego Torres Silvestre

Deep underneath the Atlantic Ocean, a massive quantity of oil lies off the Brazilian coast. According to the Energy Information Administration, Brazil has 13.2 billion barrels of proved reserves, 94 percent of which are underwater (the Brazilian estimate is closer to 17 billion barrels). In 2013, Brazil produced 2.7 million barrels of oil a day and expects to drill almost double that amount by 2020, producing up to four million barrels a day. This could add up to 660 million metric tons of carbon dioxide to annual worldwide emissions by 2035.[26]

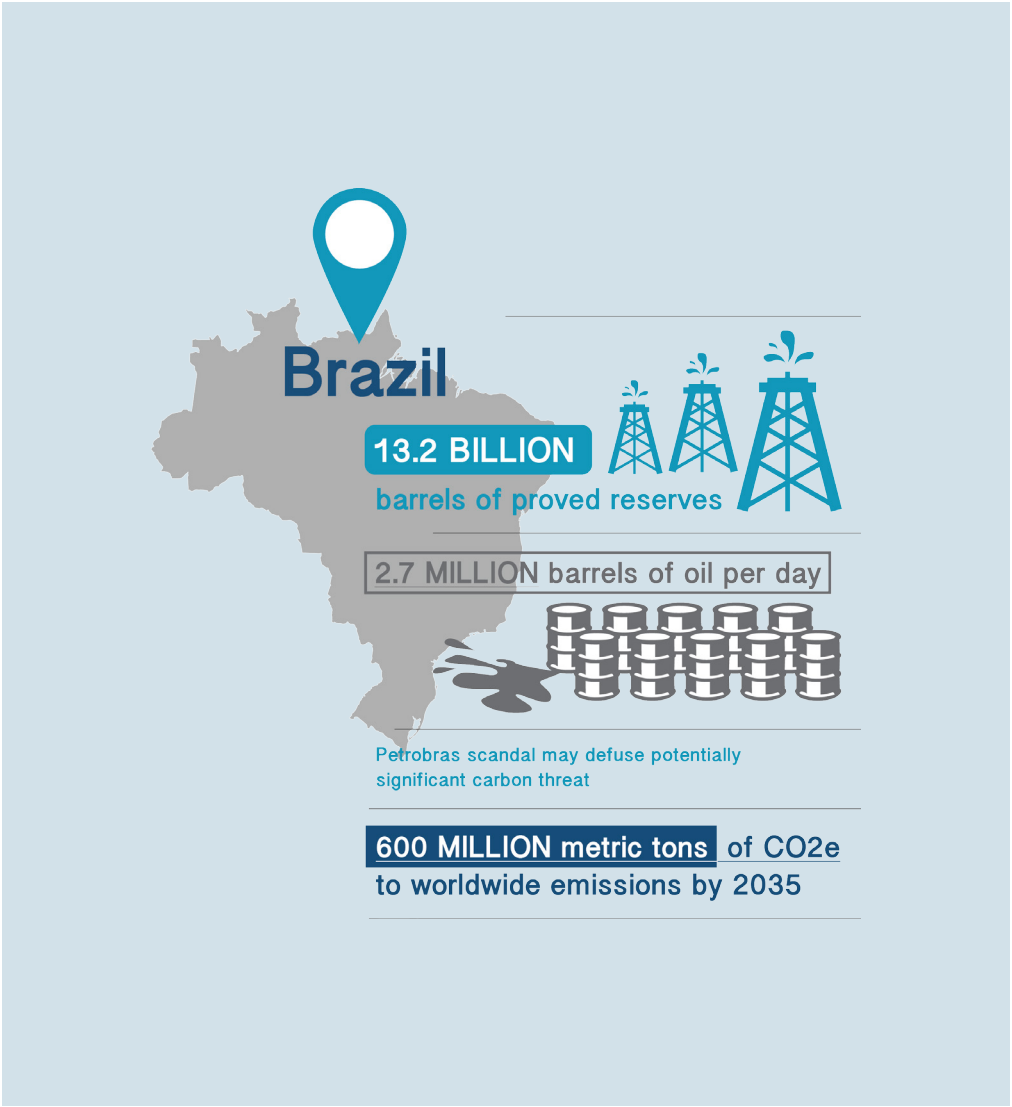
"Brazil has deep sea oil finds that are huge and that are just beginning to be exploited. Obviously, if they tap into it, there is a large amount of carbon that will go into the atmosphere."

– Jake Schmidt, international program director,
Natural Resources Defense Council

Between 2013 and 2050, the increased production and use of deep-water Brazilian oil is projected to release 17 Gt of carbon dioxide equivalent.[27]

However, a pervasive scandal involving Petrobras, the country's major oil producing company, and as many as 50 Brazilian political and business leaders—including the country's ex-president—has left Brazil reeling and the company's future as a significant oil producer uncertain. The oil giant recently cut its production target for 2020 by 3.6 percent to 2.7 million barrels a day.

Petrobras is under investigation for allegedly awarding contracts with inflated values, and then dividing the profits between its directors and the politicians. This, coupled with a worldwide decline in oil prices, has cast doubt on Brazil's potential to be major player in the world energy market and may end up defusing a potentially significant carbon threat.



Indonesia



Flickr | Marc-Andre Jung

By 2050, cumulative emissions from Indonesian coal output could reach 15.4 Gt of carbon dioxide equivalent. Only a fraction of Indonesia's coal output serves the domestic market, while almost 80 percent is exported. In 2013, over a quarter of the coal and more than one-third of the steam coal traded globally originated in Indonesia, making it the world's largest coal exporter.

Over the past two to three years, the Indonesian government has grown disillusioned with coal and mineral exports, moving toward quotas and tariffs that aim to restrict and reduce coal exports and revoke unlawfully granted mining permits.

Coal mining in Indonesia imposes enormous costs on the society in the form of water pollution, community displacement, flooding, destroyed farmland, and other serious impacts on livelihood and health. A 2014 Greenpeace investigation revealed that numerous coal mines in South Kalimantan were violating their water discharge standards, polluting the region's rivers and putting public health at risk.[28]

However, the mining industry still has significant expansion plans. Coal analysts Wood MacKenzie project that, by 2018, a scaling up of operating mines and "highly probable" projects would add 140 million metric tons of coal output over the 2013 level. Projects that are not locked in but deemed "probable" could bring the increase to 200 million metric tons by 2018.[29]

Higher-cost projects classified as "possible" are unlikely to take off, given the overcapacity in the seaborne coal market and weak outlook for demand growth, especially as China continues to reduce its dependence on coal-fired power.

The planned expansion in coal output would be solely for exports, as even the most bullish projections of domestic coal consumption put the increase by 2020 at around 50 million metric tons. That means that at current production levels without any further expansion, at least two-thirds of coal output would be exported in 2020.

In the face of the industry's expansion plans, the robust implementation and enforcement of the intentions and targets to constrain coal exports remain key challenges for the government. Furthermore, many of these projects rely on infrastructure projects that are still supported by the Indonesian government. Unless the expansion is curtailed through policies or by uncertainty over demand, the "probable" coal mining expansion could increase CO2 emissions from coal burning by 510 million metric tons per year by 2018.[30]



The African Continent



Flickr | South African Tourism

Natural gas production in Africa will deliver 64 billion cubic meters of natural gas in 2015 and rise to 193 billion cubic meters in 2035. Between 2013 and 2050 African gas will add a total of 12 Gt of CO2 equivalent emissions to the atmosphere.[31]

With a current overall electrification rate of 43 percent on the African continent, it is clear that numerous African countries are struggling to meet the energy needs of their citizens, and there is a risk that countries will turn to coal to meet their energy needs.

The current per capita emissions in low-income African countries is exceptionally low now, and population numbers are projected to increase by another one billion people by 2050. As a result, the long-term potential for CO2 emission growth is significant.

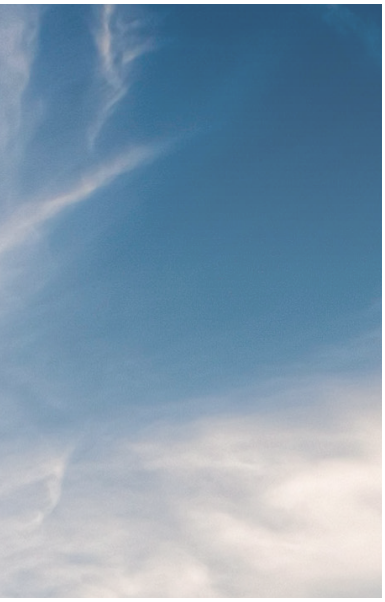
African countries must make significant investments in renewable energy capacity in order to leapfrog fossil fuels and meet their energy needs with clean energy, instead of coal or gas.

As the largest emitter on the African continent and one of the top ten coal-exporting countries in the world, South Africa's coal expansion plans are a major factor in the future emissions of the African continent. This further increases the importance of prioritizing African investments in renewable energy over more investments in coal.

"The true costs of coal are colossal: coal extraction and use damages people's health, uses up and pollutes scarce water resources, and drives climate change. The African continent is hugely vulnerable to climate change, but clearly has the potential to leapfrog dependencies on dirty and dangerous energy choices like coal. The energy choices that are made now will determine the continent's energy future. They will affect standards of living, levels of job creation, energy access and security, the environment, and the continent's economic future. Now is the time for change, and to keep oil, gas and coal reserves in the ground. As the continent's major emitter, it is essential that South Africa take its responsibility to urgently move away from fossil fuels in a just transition towards renewable energy much more seriously."

- Lindlyn Moma, Program Director,
Greenpeace Africa

Saudi Arabia



Despite remarks by Saudi Arabia's Minister of Petroleum and Natural Resources Ali al-Naimi that Saudi Arabia could phase out the use of fossil fuels by 2050, the oil-producing nation has been working hard to promote and extend global dependence on this fossil fuel.

Saudi Arabia had 268 billion barrels of crude oil in proven reserves in 2015, according to the US Energy Information Administration (EIA), second only to Venezuela. If Saudi Arabia were to burn through all its crude oil reserves, 115.24 Gt of CO2 would be released.[32] In 2012, Saudi Arabia was the fifth biggest exporter of refined oil in the world.

In July 2015, Saudi Arabia reached a record high production rate of 10.3 million barrels per day. Production has since tapered off, as oil prices have fallen worldwide. But the country is still extracting fossil fuels for export and combustion at a rapid rate.

Russia



Russia broke oil production records four times in 2015, reaching a peak of 10.77 million barrels a day in October. Production costs remain low, and Russian tax policies provide extraction companies with a buffer against market trends, protecting the companies even when oil prices are down.

According to Russian Energy Minister Alexander Novak, this rapid production rate will only increase in 2016. Russia recently surpassed Saudi Arabia as the largest supplier of crude oil to China, the world's biggest energy consumer.

The EIA estimates that Russia has 80 billion barrels of proven oil reserves, with the potential for undeveloped reserves to be discovered in oil fields in eastern Russia, the Russian Arctic, the Caspian Sea, and Timan-Pechora. Many new projects are in development, and Russia has not signaled a willingness to move away from extractive projects, despite their participation in the Paris Climate Agreement.

If burned, Russia's existing reserves would produce 34.4 Gt of CO2.

Flickr | Wajahat Mahmood

Other Major Carbon Threats

Gulf of Mexico: Up to 2.1 million barrels of oil per day could be produced from Gulf of Mexico reserves by 2016. If developed, this new deep water oil drilling could add 350 million metric tons of CO2 emissions to the atmosphere – equal to France's total emissions in 2010.[33] Between 2013 and 2050, the Gulf's oil drilling would produce 12 Gt of CO2 equivalent.

In spring 2016, the Obama administration will lease 42 million acres of the Gulf, which could result in the production of 460 to 894 million barrels of oil and 1.9 to 3.9 trillion cubic feet of natural gas.

Turkmenistan, Azerbaijan, Kazakhstan: More than 100 billion cubic meters of natural gas is set for extraction from the Caspian Sea by 2020. If completed, projects in this region would add 240 million metric tons of CO2 emissions.[34] Between 2013 and 2050, Caspian gas is expected to produce 10 Gt of CO2 equivalent.

Iraq: By 2016, new production is expected to produce 1.9 million barrels of oil a day, increasing to 4.9 million barrels a day by 2035. By 2020, Iraqi oil production could emit 420 million metric tons of CO2. Between 2013 and 2050, cumulative emissions could total 21.2 Gt of CO2 equivalent.[35]

Carbon Sinks at Risk

Burning fossil fuels is not the only way to release carbon and methane into the atmosphere. Carbon sinks like forests, peat bogs, and permafrost lock away greenhouse gases that contribute to climate change. But a warming planet melts permafrost and dries out bogs, triggering the release of greenhouse gases and accelerating the warming cycle.

Deforestation

Shifting land use patterns are responsible for a large proportion of global carbon emissions. Forests are thought to absorb as much as 30 percent of manmade emissions each year.

In a study of 2.5 million hectares of tropical forest across 75 different countries, researchers calculated that forests sequestered 247 Gt of carbon. If destroyed through deforestation or wildfires, these forests would turn from carbon sinks into major sources of atmospheric carbon. Deforestation accounts for an estimated 10 to 20 percent of all manmade emissions. The conversion of forests to land for agriculture produced four Gt of carbon dioxide equivalent per year from 2001 to 2010.

The Amazon: The nine-nation network of Amazonian indigenous territories and protected natural areas contains 55 percent of the carbon stored in the Amazon. The indigenous territories alone store more forest carbon than some countries, including tropical countries like Indonesia and the Democratic Republic of the Congo.[36] The territory is under serious threat from illegal logging, mining, dams and agricultural projects. Overall, the Amazon is estimated to store 25 percent of all the carbon absorbed by natural sinks every year. This forest must be protected to ensure the stability of the global climate.

Indonesia: Deforestation rates in Indonesia are estimated at 1.17 million hectares per year, placing the third-largest tropical rainforest on the planet in jeopardy. Indonesia has a moratorium on the issuance of new licenses for development of primary growth forests or peat land, which was extended in May 2015 for another two years by the president but studies have questioned its efficacy to date.

The Congo River Basin: Similarly, in the Congo River Basin, plans for extensive agriculture could release huge amounts of carbon. The Democratic Republic of the Congo is the fourth largest carbon reservoir in the world, locking away 8 percent of the globe's forest-stored carbon. The rainforest covers 86 million hectares (about 40 percent of the country). About 60 million hectares are threatened by logging.[37]

"There are massive plans to convert [the rainforest] to plantations for agriculture [including palm oil trees] for palm oil. If this actually happens, it will unleash large amounts of carbon from chopping down the rainforest. The carbon is embedded in the woods. Once you cut the rainforest down, and burn it, all that carbon now in the trees is in the atmosphere."

- Jake Schmidt, international program director,
Natural Resources Defense Council

Drying Peat Lands

Found on all seven continents, peat is a deposit of plant material and organic matter mixed with soil that is too wet to support decomposition. Approximately 500 to 600 Gt of carbon is stored in peatlands worldwide. Peatlands make up about 4 to 6 percent of the Earth's land surface but store 20 to 25 percent of the world's soil carbon.

Peatlands are especially sensitive to drought, as drying allows oxygen to permeate the peat layer and inhibit carbon storage. As the planet warms and precipitation patters shift, peat-rich areas will become increasingly prone to drying and burning. Peat fires, which burn through carbon stores thousands of years old, have a larger carbon footprint than any other type of wildfire.

In 1997 and 1998, huge fires in Indonesia burned almost 25 million acres of peatland. A Nature analysis from 2002 estimated that those fires released as much carbon as 13 to 40 percent of the entire annual global fossil fuels emissions, and were largely responsible for the largest recorded yearly increase in atmospheric CO2 concentration since record keeping began in 1957.[38] Currently, peat fires are thought to account for 27 percent of Indonesia's carbon emissions.

Thawing Permafrost

Nearly a fourth of the Northern Hemisphere's land surface is covered in permanently frozen soil (permafrost). Permafrost is loaded with carbon-rich plant material, enough to double the amount of heat-trapping carbon in the atmosphere if melted.[39] Scientists estimate that about 50 percent of all global belowground carbon (approximately 1672 Gt) is stored in northern permafrost.

A 2013 study warned that 1.5°C of warming would be enough to melt the permafrost in Siberia, prompting the eventual release of hundreds of gigatons of carbon dioxide and methane, with grave consequences for the climate.

In the Arctic, melting permafrost is releasing large amounts of methane and carbon dioxide into the atmosphere, creating a feedback loop that will prompt additional warming. A recent study examined 71 wetlands worldwide and found that melting permafrost is creating wetlands known as fens, which emit large amounts of methane.

Another troubling feedback loop occurs in the permafrost itself, where warming temperatures trigger microbic decomposition, which produces heat and causes further thawing. Permafrost is expected to transition from a carbon sink to a carbon source before 2100.

Methane Hydrates

Very large amounts of methane are stored around the world in the sea floor in the form of solid methane hydrates, also known as clathrates. These structures form when huge amounts of methane are exposed to water under low temperatures and high pressure, creating an ice-like structure. Climate change and warming ocean waters, however, could cause the hydrates to destabilize on their own, releasing methane and further triggering warming.

Due to their extensive storage of methane gas, these formations are under consideration as a new source of fossil fuel energy. If developed, global methane hydrate reserves could release between 1000 to 5000 Gt of carbon.

"These are naturally occurring, with the potential to become huge bombs. If they are released, they could dwarf the effects of what humans have been doing."

– Melanie Fitzpatrick, a climate scientist,
the Union of Concerned Scientists

Conclusion

The adoption of the Paris Climate Agreement marks a historic turning point in the climate movement and provides a pathway for the world to follow to reach a final, lasting resolution to climate change. In addition to the Paris agreement, there were a number of key victories globally in 2015, in the U.S. these included: the closure of the 200th American coal-fired power plant; the White House rejection of Keystone XL; and Royal Dutch Shell's retreat from the Arctic.

Building on these victories, the climate movement must now turn their attention to the projects reviewed in this report. Ensuring that these fossil fuel reserves are kept in the ground will prevent warming beyond 2°C, securing a livable future.

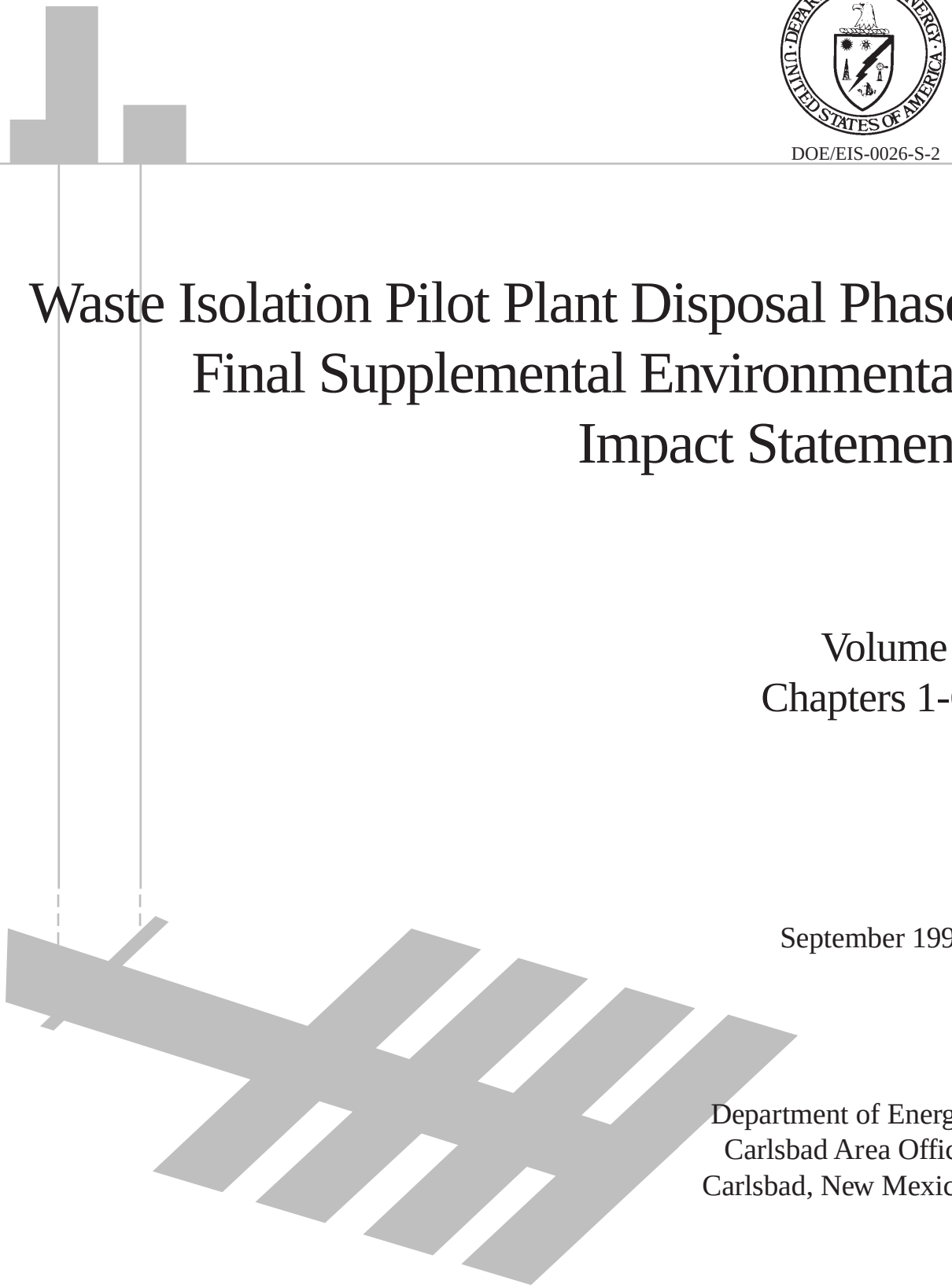
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   Emission factors for additional developments were sourced from the Ecofys report. The emission factors include uplifts for upstream emissions, including non-CO2 greenhouse gases, based on a literature review carried out by Ecofys.
   The additional coal supply from the coal projects included in the report is within the demand growth projection for the Asia-Pacific region in the IEA Current Policies scenario, which is in line with 5-6 degrees Celsius global warming. For India, two different developments, coal mining and coal-fired power plant expansion, are included. These are not double counted, but the larger of the GHG emissions associated with the two is used in the totals for each year.
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17. CO2 emission trajectory in Meindertsma et al 2012 updated to reflect a projected increase in output from 3.36Gt in 2013 to 4.0Gt in 2020. The basis for the increase is that the 14 "coal bases" produced 3.36 bln t coal in 2013 (http://www.coal.com.cn/CoalNews/ArticleDisplay_379234.html), the target is for these bases to produce 95 percent of national total coal output in 2020, and coal consumption target for 2020 is 4.2Gt (State Council Energy Strategy for 2014-2020. http://www.gov.cn/zhengce/content/2014-11/19/content_9222.htm).
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Keep It in The Ground was authored by Marlene Cimons and edited by Jeff Nesbit.



DOE/EIS-0026-S-2

Waste Isolation Pilot Plant Disposal Phase Final Supplemental Environmental Impact Statement

Volume I
Chapters 1-6

September 1997

Department of Energy
Carlsbad Area Office
Carlsbad, New Mexico

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Abstract:

The purpose of *the Waste Isolation Pilot Plant Disposal Phase Final Supplemental Environmental Impact Statement* (SEIS-II) is to provide information on environmental impacts regarding the Department of Energy's (DOE) proposed disposal operations at WIPP. To that end, SEIS-II has been prepared to assess the potential impacts of continuing the phased development of WIPP as a geologic repository for the safe disposal of transuranic (TRU) waste. SEIS-II evaluates a Proposed Action, three Action Alternatives based on the waste management options presented in the *Final Waste Management Programmatic Environmental Impact Statement*, and two No Action Alternatives. The Proposed Action describes the treatment and disposal of the Basic Inventory of TRU waste over a 35-year period. The Basic Inventory is that waste currently permitted in WIPP based on current laws and agreements. The Action Alternatives propose the treatment of the Basic Inventory and an Additional Inventory as well as the transportation of the treated waste to WIPP for disposal over a 150- to 190-year period. The three Action Alternatives include the treatment of TRU waste at consolidation sites to meet WIPP planning-basis Waste Acceptance Criteria, the thermal treatment of TRU waste to meet Land Disposal Restrictions, and the treatment of TRU waste by a shred and grout process. The No Action Alternatives propose the dismantling and closure of WIPP and storage of the waste. One No Action Alternative proposes treating the waste thermally before placing it in retrievable storage.

SEIS-II evaluates environmental impacts resulting from the various treatment options; the transportation of TRU waste to WIPP using truck, a combination of truck and regular rail service, and a combination of truck and dedicated rail service; and the disposal of this waste in the repository. Evaluated impacts include those to the general environment and to human health. Additional issues associated with the implementation of the alternatives are discussed to provide further understanding of the decisions to be reached and to provide the opportunity for public input on improving DOE's Environmental Management Program.

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GLOSSARY

actinide	An element in the series beginning with element 89 (actinium) and continuing through element 103 (lawrencium). All the transuranic nuclides considered in this document are actinides.
activity	A measure of the rate at which a material emits nuclear radiation, usually given in terms of the number of nuclear disintegrations occurring in a given length of time. The common unit of activity is the curie, which amounts to 37 billion disintegrations per second. The International Standard unit of activity is the becquerel and is equal to one disintegration per second.
aerosolize	The process of converting a solid or a liquid into an airborne suspension of fine particles (an aerosol).
aggregate	The sum total; for purposes of SEIS-II, the accumulated effect or quantity by successive additions, often over time.
air quality	A measure of the quantity of pollutants in the air.
alluvium	Clay, silt, sand, and/or gravel deposits found in a stream channel or in low parts of a stream valley that is subject to flooding. Ancient alluvium deposits frequently occur above the elevation of present-day streams.
alpha particle	A positively charged particle emitted in the radioactive decay of certain nuclides. Made up of two protons and two neutrons bound together, it is identical to the nucleus of a helium atom.
ambient air	The surrounding atmosphere, usually the outside air, as it exists around people, plants, and structures. It is not the air in immediate proximity to emission sources.
anhydrite	A mineral consisting of anhydrous calcium sulfate: $CaSO_4$.
aqueous	Related to water.
aquifer	Geologic unit sufficiently permeable to conduct groundwater.
argillaceous rocks	Rocks containing appreciable amounts of clay.
atmosphere	The layer of air surrounding the earth.
atmospheric dispersion	Movement of a contaminant as a result of the cumulative effect of the random motions of the air. Equivalent to eddy diffusion.
atom	Smallest unit of an element that is capable of entering into a chemical reaction and displays the other properties of the element.

backfill	Materials, such as salt or a mixture of salt and other materials, used to reduce void volumes in storage panels or drifts.
background radiation	Radiation from: (1) naturally occurring radioactive materials, as they exist in nature prior to removal, transport, or enhancement or processing by man; (2) cosmic and natural terrestrial radiation; (3) global fallout as it exists in the environment; (4) consumer products containing nominal amounts of radioactive material or emitting nominal levels of radiation; and (5) radon and its progeny in concentrations or levels existing in buildings or the environment that have not been elevated as a result of current or past human activities.
basin	A topographic or structurally low area compared to the immediately adjacent areas.
bedded	Arranged in layers or beds. Usually, but not exclusively, applied to sedimentary deposits.
Bell Canyon Formation	A sequence of rock strata that forms the topmost unit of the Delaware Mountain Group.
berm	An earthen enbankment; a long artificial mound of stone or earth similar to a dike or levee.
bound	To estimate or describe an upper limit on a potential environmental consequence when uncertainty exists.
bounding	That which represents the maximum reasonably foreseeable event or impact. All other reasonably foreseeable events or impacts would have fewer and/or less severe environmental consequences.
°C	Degree Celsius. °C = 5/9 x (°F - 32).
caliche	Calcium carbonate ($CaCO_3$) deposited in the soils of arid or semiarid regions.
cancer	Any malignant new growth of abnormal cells or tissue.
canister	In this document, a container, usually cylindrical, for remotely handled transuranic waste. The waste will remain in this canister during and after emplacement at Waste Isolation Pilot Plant. A canister affords physical containment but not shielding; shielding is provided during shipment by a cask.
carcinogen	An agent capable of producing or inducing cancer.
carcinogenic	Capable of producing or inducing cancer.

cask	A massive shipping container providing shielding for highly radioactive materials and holding one canister.
Castile Formation	A Permian age rock unit of evaporites (interbedded halite and anhydrite) that immediately underlies the Salado Formation, the rock unit in which disposal rooms are excavated.
cloudshine	The pathway of direct external dose from the passing cloud of dispersed radioactive material.
commercial waste	Nuclear waste deriving from commercial sources. These are principally power reactors, but also include research laboratories and medical facilities.
committed dose equivalent	The predicted dose equivalent to a tissue or organ over a 50-year period after an intake of a radionuclide into the body. It does not include dose contributions from radiation sources external to the body. Committed dose equivalent is expressed in units of rem (or sievert). (1 rem = 0.01 sievert).
committed effective dose equivalent	The sum of the committed dose equivalents to various organs or tissues in the body from radioactive material taken into the body, each multiplied by the tissue-specific weighting factor. Committed effective dose equivalent is expressed in units of rem (or sievert).
community	A group of people or a site within a spatial scope exposed to risks that potentially threaten health, ecology, or land values, or exposed to industry that stimulates unwanted noise, odors, industrial traffic, particulate matter, or other nonaesthetic impacts.
concentration	The amount of a substance contained in a unit quantity (mass or volume) of a sample.
conservative	When used with predictions or estimates, leaning on the side of pessimism. A conservative estimate is one in which the uncertain inputs are used in the way that provides a reasonable upper limit of the estimate of an impact.
contact-handled transuranic waste	TRU waste that does not require shielding other than that provided by its container to protect those handling it from radiation exposure. The radiation level at the outer surface of the container is specified as no more than 200 millirem per hour.
containment	Retention of a material or substance within prescribed boundaries.
contamination	The presence of excess radioactive material from a U.S. Department of Energy activity in or on a material or property.

creep	The continuous, usually slow deformation of solid rock resulting from constant strain acting over a long period of time. Salt will creep much faster than limestone, in a manner similar to ice in a glacier.
creep closure	Closure of underground openings, especially openings in salt, by creep flow of the surrounding rock under lithostatic pressure.
criteria pollutants	Six pollutants (ozone, carbon monoxide, total suspended particulates, sulfur dioxide, lead, and nitrogen oxide) known to be hazardous to human health and for which the U.S. Environmental Protection Agency sets National Ambient Air Quality Standards under the Clean Air Act.
critical habitat	The specific areas within the geographical area occupied by a species at the time it is listed as threatened or endangered on which are found those physical or biological features that are essential to the conservation of the species and that may require special management considerations or protection. It also includes specific areas outside the geographical area occupied by the species at the time it is listed if these areas are determined to be essential for the conservation of the species.
criticality	A state in which a self-sustaining nuclear chain reaction is achieved.
Culebra Dolomite	The lower of two geologic units of water-bearing dolomite within the Rustler Formation.
cumulative impacts	Cumulative impacts are those impacts on the environment that result from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.
curie	A unit of radioactivity equal to 37 billion (3.7×10^{10}) disintegrations per second.
Darcy's law	A mathematical relationship that describes the flow through porous media.
decommissioning	The removal from active service of a facility.
decontamination	The removal of unwanted material (especially radioactive material) from the surface or from within another material.
defense waste	Nuclear waste deriving from the manufacture of nuclear weapons and the operation of naval reactors. Associated activities, such as the research carried on in the weapons laboratories, also produce defense waste.
degradation	A process of transition. To decompose (a compound) by stages.

Delaware Basin	An area in southeastern New Mexico and the adjacent parts of Texas where the Permian sea deposited a large thickness of evaporites some 220 to 280 million years ago. It is partially surrounded by the Capitan Reef.
design life	The design life of components or systems generally refers to the estimated minimum period of time that the component or system is expected to perform within specifications before the effects of aging result in performance deterioration or a requirement to replace the component or system.
diffusion	Movement of atoms, ions, or molecules of one substance into or through another as a result of thermal or concentration gradients.
diffusion, molecular	Movement of a contaminant as the result of the cumulative effect of the random motions of molecules along a concentration or thermal gradient.
disposal	In this document, permanent disposition of waste in a repository. Use of the word disposal" implies that no need for later retrieval is expected. It also implies a minimal need for surveillance.
Disposal Phase	The period in which the U.S. Department of Energy proposes to permanently emplace transuranic wastes in the Waste Isolation Pilot Plant.
dissolution	The process whereby a material is taken into solution. Selective dissolution of minerals may produce cavities and caves, or enlarged fractures in a rock formation.
dissolution front	The boundary of a geologic region within which rock is dissolving. In this document, the term particularly refers to the wedge-like leading edge of salt dissolution at the interface between the Rustler and Salado Formation.
distribution coefficient	In an aquifer, the ratio of the concentration of a substance absorbed by the rock to the concentration of the substance remaining in solution. A large distribution coefficient implies that the substance moves much more slowly than the groundwater. It is measured in units of cubic centimeters per gram or equivalent.
disturbed rock zone	The disturbed rock zone is a volume of rock adjacent to an underground excavation in which mechanical properties (e.g., elastic modulus) and hydraulic properties (e.g., permeability and degree of saturation) have been changed because of the excavation.
dolomite	A sedimentary rock consisting primarily of the mineral dolomite: $CaMg(CO_3)_2$.
dose (absorbed dose)	The energy imparted to matter per unit mass by ionizing radiation. The unit of absorbed dose is the rad (or gray [Gy]). In SEIS-II, it is used as a general term for dose equivalent, total effective dose equivalent, and committed dose equivalent.

dose conversion factor	A numerical factor used in converting radionuclide intake (curies) in the body to the resultant dose equivalence (rem or person-rem).
dose equivalent	The product of absorbed dose in rad (or gray) in tissue and a quality factor. Dose equivalent is expressed in units of rem (or sievert).
dose rate	The radiation dose delivered per unit time (e.g., rem per hour).
dual porosity	Having fracture porosity as well as interconnected pores (matrix porosity).
ecology	The science dealing with the relationship of all living things with each other and with the environment.
economic sector	A distinctive part of the economy of a geographic region defined by a standard industrial classification scheme. One such scheme defines "major" sectors and divides them into subsectors; for example, the major sector "trade" contains the subsectors "wholesale trade" and "retail trade." Another classification scheme specifies "primary" and "secondary" sectors; the criterion for including a sector in the primary classification is that its level of activity is generally not controlled by the level of economic activity in the region; a primary industry, in other words, produces goods and services for export from the region.
effective dose equivalent	The sum of the products of the dose equivalent received by specified organs or tissues of the body and a tissue-specific weighting factor. The effective dose equivalent is expressed in units of rem (or sievert).
effluent	Liquid or airborne material released to the environment. In common usage, however, the term "effluent" implies liquid release.
EIS	Environmental impact statement; a document required by the National Environmental Policy Act for proposed major Federal actions involving potentially significant environmental impacts.
E/Q (E over Q)	A measure of atmospheric dispersion for short-term (acute) atmospheric releases using gaussian dispersion plume modeling, with units of s/m^3. For a given point or location at some distance from the source, it represents the time-integrated air concentration ($Ci \bullet s/m^3$) divided by the total release from the source (Ci). Integrated air concentrations used are usually plume centerline values. E/Qs are typically used for releases lasting no longer than 8 to 24 hours.
element	One of the known chemical substances that cannot be divided into simpler substances by chemical means.
endangered species	Plants and animals that are threatened with extinction, serious depletion, or destruction of critical habitat. Requirements for declaring a species endangered are contained in the Endangered Species Act.

energy	The capacity for doing work.
environment	The sum of all external conditions and influences affecting the life development and, ultimately, the survival of an organism.
environmental monitoring	The act of measuring, either continuously or periodically, some quantity of interest, such as radioactive material in the air.
ephemeral stream	A stream channel that carries water only during part of the year, immediately after periods of rainfall or snowmelt.
equilibrium	A state of rest in a chemical or mechanical system. Chemical: The state of a reaction in which its forward and reverse reactions occur at equal rates so that the concentrations of the reactants do not change with time. Mechanical: Forces in one direction are equal and opposite to those in the opposing direction. Flow of salt to fill the excavated cavity is an attempt by the salt to reattain a state of mechanical equilibrium.
erosion	Removal and transport of materials by wind, ice, or water on the earth's surface.
evaporite	A sedimentary rock composed primarily of minerals produced by partial or total evaporation of sea water.
evapotranspiration	Loss of water from the earth's surface to the atmosphere by a combination of evaporation from the soil, lakes, streams, and transpiration from plants.
exposure	A measure of the ionization produced in air by X or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of the air in the volume element.
°F	Degree Fahrenheit. °F = (°C x 9)/5 + 32.
fault	A fracture or a zone of fractures along which there has been displacement parallel to the fracture.
fissile	Describes a nuclide that undergoes fission upon absorption of neutrons of any energy.
fission (nuclear)	The splitting of a heavy nucleus typically into two approximately equal parts (infrequently three parts), which are nuclei of lighter elements, accompanied by the release of energy and generally one or more neutrons. Fission can occur spontaneously or can be induced by nuclear bombardment.
fission product	An element or compound resulting from fission.

formation	A mappable geologic body of rock identified by lithic characteristics and stratigraphic position. Formations may be combined into groups or subdivided into members.
40 CFR Part 191	The U.S. Environmental Protection Agency standard for managing and disposing of spent nuclear fuel and high-level and transuranic wastes. Subpart A deals with managing and storage of wastes, while Subpart B covers long-term isolation and disposal.
fraction	A small part of the total. The particulate fraction is that part of the waste in a particulate form.
gamma	Short-wavelength electromagnetic radiation (high-energy photons) emitted in the radioactive decay of certain nuclides. Gammas are the same as gamma rays or gamma waves.
geology	The science that deals with the earth; the materials, processes, environments, and history of the planet, especially the lithosphere, including the rocks, their formation, and structure.
gross alpha	The total rate of alpha particle emission from a sample, without regard to energy distribution or source nuclides.
gross beta	The total rate of emission of beta particles from a sample, without regard to energy distributions or source nuclides.
groundshine	The pathway of direct external dose from radioactive material that has deposited on the ground after being dispersed from the accident site.
groundwater	All subsurface water, especially that contained in the saturated zone below the water table.
gypsum	A soft mineral consisting of hydrous calcium sulfate: $CaSO_4 \cdot 2H_2O$.
habitat	The part of the physical environment in which a plant or animal lives.
half-life	Time required for a radionuclide to lose 50 percent of its activity by decay. Each radionuclide has a unique half-life; that is, half of a particular radionuclide will decay in a specified amount of time; then half of the remaining portion will decay in the same amount of time, and so on. Half-life can also refer to the length of time that a chemical/radionuclide/ biological agent remains in the body. Each material has biologically unique half-lives, depending on the substance, the organ of concern, and its route of elimination.
halite	A mineral composed of sodium chloride, NaCl.

hazard index	An indicator of the potential toxicological hazard from exposure to a particular substance. The hazard index is equal to an individual's estimated exposure divided by the U.S. Environmental Protection Agency's substance-specific reference dose.
hazardous waste	Hazardous constituents regulated by the Resource Conservation and Recovery Act and defined in 40 CFR 261 Subparts C and D.
head	When used in a hydraulic sense, it is understood to mean static head. The static head is the height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point.
headspace	The space between the container lid and the waste inside the container.
high efficiency particulate air filter	This filter is designed to remove 99.9 percent of particles as small as 0.3 micrometer in diameter from a flowing air stream.
high-level waste	The highly radioactive waste material that results from the reprocessing of spent nuclear fuel. High-level waste may include other highly radioactive material that the U.S. Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation.
historic resources	The sites, districts, structures, and objects associated with historic events, persons, or social or historic movements.
horizon	A particular layer in a sequence of rock units. The waste-emplacement horizon in the Waste Isolation Pilot Plant is a specific level about 655 meters (2,150 feet) below the surface in the Salado Formation at which openings are being excavated for waste disposal.
hot cell	A heavily shielded enclosure for handling and processing (by remote means or automatically) or storing highly radioactive materials.
hydraulic conductivity	A quantity that describes the rate at which water flows through an aquifer. It has units of length/time and is equal to the hydraulic transmissivity divided by the thickness of the aquifer.
hydraulic gradient	A quantity that describes the rate of change of pressure head per unit of distance of flow at a given point and in a given direction.
igneous	A rock or mineral that crystallizes from magma, molten rock.
immediately dangerous to life and health	A term that represents a maximum airborne concentration from which one could escape within 30 minutes without any escape-impairing symptoms or any irreversible health effects.

in situ	In the natural or original position; i.e., in place.
intensity (earthquake)	A measure of the effects of an earthquake on humans and structures at a particular place. It is measured in numerical units on the modified Mercalli scale.
interbed	A bed of one kind of rock occurring between or alternating with beds of another rock type.
ionization	The process that creates ions. Nuclear radiation, X-rays, high temperatures, and electric discharges can cause ionization.
ionizing radiation	Radiation capable of displacing electrons from atoms or molecules to produce ions.
isotope	An atom of a chemical element with a specific atomic number and atomic weight. Isotopes of the same element have the same number of protons but different numbers of neutrons. Isotopes are identified by the name of the element and the total number of protons and neutrons in the nucleus. For example, uranium-235 is an isotope of uranium with 92 protons and 143 neutrons and uranium-238 is an isotope of uranium with 92 protons and 146 neutrons.
karst	A topography characterized by sinkholes, caves, and disappearing streams formed by dissolution in limestone, dolomite, and evaporite bedrock.
kelvin	A unit of temperature, abbreviated K, equal to the degree Celsius expressed as: $°K = °C + 273$.
lag storage	The storage of TRU waste that has been certified to the WAC and is awaiting shipment to the WIPP facility for disposal.
latent cancer fatalities	Deaths resulting from cancer that has become active after a latent period following radiation exposure. Latent cancer fatalities can be calculated for the public by using the risk conversion factor of 5×10^{-4} deaths per person-rem and for the worker by using the risk conversion factor of 4×10^{-4} deaths per person-rem.
leaching	The process of extracting a soluble component from a solid by the percolation of a solvent, such as water, through the solid.
lineament	A geologic term for straight or gently curved, linear topographic features.
lithostatic pressure	The vertical pressure at a point in the earth's crust equal to the weight of the overlying column of rock.
Los Medaños	The area in southeastern New Mexico surrounding the Waste Isolation Pilot Plant site. In English, it means "dune country."

low-income population	A population where 25 percent or more of the population is identified as living in poverty.
low-level waste	Radioactive waste not classified as high-level waste, transuranic waste, or uranium or thorium mill tailings.
Magenta Dolomite	The upper of the two dolomite layers within the Rustler Formation that are locally water-bearing.
magnitude (earthquake)	A measure of the total energy released by an earthquake. It is commonly measured in numerical units on the Richter scale. Each unit, e.g. 7, is different from an adjacent unit by a factor of 30.
maximally exposed individual (MEI)	A hypothetical member of the public who is exposed to a release of radioactive or chemically hazardous material in such a way (by combination of location, dietary habits, etc.) that the individual will likely receive the maximum dose from such release.
member	A division of a formation differentiated by separate or distinct lithology or complex of lithologies.
migration	The natural travel of a material through the air, soil, or groundwater.
mitigate	To take practicable means to avoid or minimize environmental harm from a selected alternative.
molecular weight	The weight of a molecule of a chemical expressed in atomic mass units.
Nash Draw	A shallow 8-kilometer- (5-mile-) wide valley open to the southwest located to the west of the Waste Isolation Pilot Plant site.
National Environmental Policy Act	This Act was designed to promote inclusion of environmental concerns in Federal decision-making.
National Register of Historic Places	A list maintained by the National Park Service of architectural, historic, archaeological, and cultural sites of local, state, or national importance.
noninvolved worker	For this document, a worker who is not involved in the operation of a facility when a radioactive release occurs.
NO_x	Oxides of nitrogen, primarily nitrogen oxide and nitrogen dioxide. These are produced primarily by combustion of fossil fuels, and can constitute an air pollution problem.

nuclide	A species of atom, characterized by its number of protons, number of neutrons, and energy state.
order of magnitude	A multiple of ten. When a measurement is made with a result such as 3×10^7, the exponent of 10 (here 7) is the order of magnitude of that measurement. To say that this result is known to within an order of magnitude is to say that the true value lies between (in this example) 3×10^6 and 3×10^8.
organic compounds	Of or designating carbon compounds. (Some simple compounds of carbon, such as carbon dioxide, are frequently classified as inorganic compounds.)
overpack	A container put around another container. In the Waste Isolation Pilot Plant, overpacks would be used on damaged or otherwise contaminated drums, boxes, and canisters that would not be practical to decontaminate.
oxide	A compound consisting of an element combined with oxygen.
ozone	A molecule of oxygen in which three oxygen atoms are chemically attached to each other.
package	In the regulations governing the transportation of radioactive materials, the packaging together with its radioactive contents as presented for transport.
packaging	A shipping container without its contents.
particulates	Solid particles and liquid droplets small enough to become airborne.
PE-Ci	Plutonium-239 equivalent curies are used as a radioactive hazard index factor that relates the radiotoxicity of transuranic radionuclides to that of plutonium-239.
permeability	The capability of a soil or rock to transmit a fluid.
person-rem	A measure of the radiation dose to a given population; the sum of the individual radiation doses received by that population.
pH	A measure of the hydrogen ion concentration in aqueous solution. Pure water has a pH of 7, acidic solutions have a pH less than 7, and alkaline solutions have a pH greater than 7.
physiographic	Geographic regions based on geologic setting.

planning-basis Waste Acceptance Criteria	The U.S. Department of Energy document, currently in revision number 5, that describes the criteria by which unclassified transuranic waste will be accepted for emplacement at the Waste Isolation Pilot Plant and the basis on which these criteria were established. The current planning-basis for waste acceptance criteria is a compendium of the minimal requirements established by law, regulation, and U.S. Department of Energy orders that transuranic waste must meet to be transported to and disposed of at the Waste Isolation Pilot Plant. The treatment selected pursuant to the Supplemental Environmental Impact Statement-II analyses could result in modifications to the waste acceptance criteria.
PM_{10}	Particulate matter with a 10-micron or less aerodynamic diameter.
point source	A source of effluents that is small enough in dimensions that it can be treated as if it were a point. The converse is a diffuse source. A point source can be either a continuous source or a source that emits effluents only in puffs or for a short time.
pollution	The addition of an undesirable agent to the environment in excess of the rate at which natural processes can degrade, assimilate, or disperse it.
polyhalite	A relatively hard and brittle evaporite mineral: $K_2MgCa_2(SO_4)_4 \cdot 2H_2O$. In the Delaware Basin, it is often associated with anhydride.
population dose	The sum of the radiation doses received by the individual members of a population.
population-weighted E/Q	A measure of the atmospheric dispersion across an entire populated sector following an acute release. For a given 22.5° compass sector, it is the sum of the product of the E/Q and the population for each of the ten segments comprising the sector, with units of person•s/m^3. (See also E/Q [E over Q].)
porosity	Percentage of void space in a material.
potash	Potash is the common industrial term for potassium in various chemical combinations with sodium, magnesium, chlorine, and sulfate.
potentiometric surface	Surface to which water in an aquifer would rise by hydrostatic pressure. It is usually represented in figures as a contour map, in which each point indicates how high the water would rise in a well tapping that aquifer at that point.
progeny	Stable or radioactive elements formed by the radioactive decay of another nuclide, which is the "parent."
pyrophoric	Spontaneously igniting in air; producing sparks by friction.

Quality Factor	A modifying factor used to calculate the dose equivalent from absorbed dose. The quality factor can vary by type and energy of the ionizing radiation.
radiation	Ionizing radiation; e.g., alpha particles, beta particles, gamma rays, X-rays, neutrons, protons, and other particles capable of producing ion pairs in matter. As used in this document, radiation does not include nonionizing radiation.
radioactive decay	The spontaneous transformation of one nuclide into a different nuclide or into a different state of the same nuclide. The process results in the emission of nuclear radiation (alpha, beta, or gamma radiation).
radioactive waste	Materials from nuclear operations that are radioactive or are contaminated with radioactive materials and for which there is no practical use or for which recovery is impractical.
radioactivity	The property or characteristic of radioactive material to undergo spontaneous transformations ("disintegrations" or "decay") with the emission of energy in the form of radiation. It means the rate of spontaneous transformations of a radionuclide. The unit of radioactivity is the curie (or becquerel). (1 curie = 3.7×10^{10} becquerel).
radionuclide	A nuclide that emits radiation by spontaneous transformation.
radionuclide inventory	A list of the kinds and amounts of radionuclides in a container or a source. Amounts are usually expressed in activity units: curies or curies per unit volume.
recharge	In groundwater hydraulics, the addition of water to the zone of saturation; also, the amount of water added.
Record of Decision	The document, publicly available, by which a Federal department or agency decides on an alternative presented and evaluated through the environmental impact statement process.
reference dose	The reference dose is an estimate of the daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a portion of the lifetime (subchronic reference dose), or during a lifetime (chronic reference dose).
rem	A common (or special) unit of dose equivalent, effective dose equivalent, or committed dose equivalent.
remote-handled transuranic waste	TRU waste that requires shielding in addition to that provided by the container to protect people nearby from radiation exposure. By definition, the radiation level at the outer surface of the container is greater than 200 millirem per hour and less than 1,000 rem per hour.

repository	A facility for disposal of radioactive waste.
reserves	Mineral resources that can be extracted profitably by existing techniques and under present economic conditions.
Resource Conservation and Recovery Act	This Act was designed to provide "cradle to grave" control of hazardous chemical wastes.
resources	Mineralization that is concentrated enough, in large enough quantity, and in a physical and chemical form such that its extraction may be possible in the future.
retrievable storage	Storage of radioactive waste in a manner designed for recovery without loss of control or release of radioactivity.
RH-72B	A packaging designed to transport remote-handled transuranic waste. The cask is a circular cylinder providing shielding from the radioactive contents. The cask is designed to provide double containment of a vented canister that is 3 meters (10 feet) long by 0.67 meter (2.2 feet) in diameter. The vented canister weighs 1,000 kilograms (2,200 pounds) and has a payload of approximately 2,631 kilograms (5,800 pounds), which is approximately 0.89 cubic meters (31 cubic feet) of waste.
risk	The likelihood of suffering a detrimental effect as a result of exposure to a hazard. In accident analysis, the probability weighted consequence of an accident, defined as the accident frequency per year multiplied by the consequence.
runoff	The portion of rainfall, melted snow, or irrigation water that flows across the ground surface and either infiltrates or eventually returns to streams.
Rustler Formation	The evaporite beds, including mudstones, of Permian age that immediately overlie the Salado Formation in which the Waste Isolation Pilot Plant disposal levels are built.
Salado Formation	The Permian Age evaporite unit within which wastes would be disposed of in the Waste Isolation Pilot Plant repository.
San Simon Swale	A broad depression about 24 kilometers (15 miles) east of the Los Medaños site, open to the southeast.
scenario	A set of conditions presumed for the purpose of estimating doses by analysis.
seismicity	All of the earthquakes that may occur in a region, regardless of magnitude.
shaft	A man-made hole, either vertical or steeply inclined, that connects the surface with an underground excavation.

shield	Material used to reduce the intensity of radiation that would irradiate personnel or equipment.
slurry	A suspension of fine particles in a liquid, in which the solid constituents are easily carried along by the liquid.
solubility	The degree to which a compound in its pure state will dissolve; water is the solvent used for determining aqueous solubility of a compound.
sorption	The binding on a microscopic scale of one substance to another, such as by adsorption or ion exchange.
source term	The kinds and amounts of radionuclides that may lead to an assumed release of radioactive material.
spent fuel or spent nuclear fuel	Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated.
storage	Temporary placement of waste in a facility. Storage usually implies the need for continued surveillance.
strata	Layers of rock.
stratigraphy	The study of layered sequences of rocks.
surface water	A creek, stream, river, pond, lake, bay, sea, or other waterway that is directly exposed to the atmosphere.
tectonic activity	Movement of the earth's crust, produced by internal forces, such as uplift, subsidence, folding, faulting, and seismic activity.
Ten Drum Overpacks	A metal container (73 inches high and 72 inches in outside diameter) similar to the standard waste box, designed to efficiently use the inner containment vessel of the TRUPACT-II. Authorized packaging configurations are as follows: ten 55-gallon drums, one standard waste box, or four 55-gallon drums within a standard waste box.
threatened species	Any species likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. Requirements for declaring a species threatened are contained in the Endangered Species Act.
throughput	The number of TRUPACT-IIs and RH-72Bs capable of being processed at the WIPP Waste Handling Building in a given time period (i.e., 50 TRUPACT-IIs and 8 RH-72Bs per week).
total effective dose equivalent	The sum of the effective dose equivalent from radiation sources external to the body during the year plus the committed effective dose equivalent from

	radionuclides taken into the body. A 50-year time interval is assumed for determining committed dose.
TRANSCOM	A satellite-based tracking and communication system established by the U.S. Department of Energy.
transmissivity	A quantity defined in the study of groundwater hydraulics that describes the rate at which water may be transmitted through an aquifer. It has units of length^2/time.
transmutation	Any process in which a nuclide is transformed into a different nuclide, or more specifically, when transformed into a different element by a nuclear reaction.
transuranic mixed waste	Transuranic waste that is commingled with Resource Conservation Recovery Act-regulated hazardous wastes as defined in 40 CFR Part 261, Subparts C and D.
transuranic radionuclide	A nuclide with an atomic number (number of protons) greater than that of uranium (92). All transuranic radionuclides are radioactive.
transuranic waste	Waste materials (excluding high-level waste and certain other waste types) contaminated with alpha-emitting radionuclides that are heavier than uranium with half-lives greater than 20 years and occur in concentrations greater than 100 nanocuries per gram. Transuranic waste results primarily from plutonium reprocessing and fabrication as well as research activities at U.S. Department of Energy defense installations.
TRUPACT	Transuranic Package Transporter.
TRUPACT-II	TRUPACT-II is the package designed to transport contact-handled transuranic waste to the Waste Isolation Pilot Plant site. It is a cylinder with a flat bottom and a domed top that is transported in the upright position. The major components of the TRUPACT-II are an inner, sealed, stainless steel containment vessel within an outer, sealed, stainless steel containment vessel. Each containment vessel is nonvented and capable of withstanding 345 kilopascals (50 pounds per square inch) of pressure. The inner containment vessel cavity is 1.8 meters (6 feet) in diameter and 2 meters (6.75 feet) tall, with a capability of transporting fourteen 0.21-cubic-meter (55-gallon) drums, two standard waste boxes, or one 10-drum overpack.
tuff	Volcanic rock formed of welded or compacted volcanic ash.
void volume	That part of the total volume not occupied by the solid volume. The void volume may contain either liquid or gas.

volatile organic compound	Any compound containing carbon and hydrogen in combination with any other element that has a vapor pressure of 77.6 millimeters of mercury (1.5 pounds per square inch) absolute or greater under actual storage conditions.
volatilization	To evaporate at normal temperatures and pressures.
vug	A cavity, often with a mineral coating of different composition than the surrounding rock.
Waste Acceptance Criteria (WAC)	A set of minimum waste characteristics criteria that the U.S. Department of Energy has established as a planning basis for waste that would be emplaced at the Waste Isolation Pilot Plant. Should disposal operations at the Waste Isolation Pilot Plant be approved, these planning-basis criteria (or some modification of them) would become the WAC. The WAC may change based on decisions in the Record of Decision for SEIS-II that change these minimum requirements.
waste form	The condition of the waste. This phrase is used to emphasize the physical and chemical properties of the waste.
Waste Isolation Pilot Plant	The facility near Carlsbad, New Mexico, that has been designated to be an operational site for evaluating disposal capabilities of bedded salt for U.S. Department of Energy-generated transuranic waste.
waste matrix	The material that surrounds and contains the waste and, to some extent, protects it from being released into the surrounding rock and groundwater. Only material within the canister (or drum or box) that contains the waste is considered part of the waste matrix.
$\overline{X}/Q'$ (chi-bar over Q prime)	A measure of the average atmospheric dispersion for long-term (chronic) atmospheric releases using a gaussian dispersion plume modeling, with units of s/m^3. For a given point or location at some distance from the source, it represents the average air concentration in Ci/m^3 divided by the release rate (Ci/s). Typically, the concentration used is the average centerline value for individuals and is averaged over a specific sector of a polar grid surrounding the release point for populations. $\overline{X}/Q'$s are used for long-term (chronic) releases, often on the order of months or years.

ACRONYMS AND ABBREVIATIONS

3D	three dimensional
µR/hr	microroentgen per hour
ACGIH	American Conference of Governmental Industrial Hygienists
AEC	U.S. Atomic Energy Commission
AIHA	American Industrial Hygiene Association
AIS	Air Intake Shaft
ALARA	as low as reasonably achievable
Ames	Ames Laboratory-Iowa State University
ANL-E	Argonne National Laboratory-East
ANL-W	Argonne National Laboratory-West
AQCR	Air Quality Control Regulations
ARCO	ARCO Medical Products Company
ATSF	Atchison, Topeka, and Santa Fe Railroad
BBER	Bureau of Business and Economic Research of the University of New Mexico
BCL	Battelle Columbus Laboratories
BEIR-III	1980 report of the Committee on Biological Effects of Ionizing Radiation of the National Academy of Sciences/National Research Council.
BEMR	Baseline Environmental Management Report
Bettis	Bettis Atomic Power Laboratory
BIR-2	Baseline Inventory Report, Revision 2
BIR-3	Baseline Inventory Report, Revision 3
BLM	U.S. Bureau of Land Management
BNL	Brookhaven National Laboratory
Bq	becquerel
BSEP	Brine Sampling and Evaluation Program
°C	degree Celsius
C&C	Agreement for Consultation and Cooperation
CAO	Carlsbad Area Office
CAST	Colorado Allstate Trucking
CCA	Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant
CCDF	Complementary Cumulative Distribution Function
CEDE	committed effective dose equivalent
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CH_4	methane
CH-TRU	contact-handled transuranic
Ci	curie
cm^2	square centimeters
CMR	Central Monitoring Room
CO	carbon monoxide
CO_2	carbon dioxide
CoC	contaminant of concern

CR	concentration ratio
CSR	Compliance Status Report
D&D	decontamination and decommissioning
DBE	design-basis earthquake
DCF	dose conversion factor
Department	U.S. Department of Energy
DDREF	Dose and Dose Rate Effectiveness Factor
DF	dose factor
DLR	Dewey Lake Redbeds
DOE	U. S. Department of Energy
DOT	U.S. Department of Transportation
DRZ	disturbed rock zone
EA	Environmental Assessment
EEG	Environmental Evaluation Group
EIS	Environmental Impact Statement
EOC	Emergency Operations Center
EPA	U.S. Environmental Protection Agency
E/Q	atmospheric dispersion factor for short-term releases
ER	environmental restoration
ERPG	Emergency Response Planning Guideline
ETEC	Energy Technology Engineering Center
°F	degree Fahrenheit
FEIS	Final Environmental Impact Statement for the Waste Isolation Pilot Plant
FEPs	features, events, and processes
FFCAct	Federal Facility Compliance Act
FGE	fissile-gram equivalent
F.I.R.E.	Fire, Insurance and Real Estate
FONSI	finding of no significant impact
FR	Federal Register
FRA	Federal Railroad Administration
ft^3	cubic feet
FY	fiscal year
GENII	Generation II Code Package
H_2S	hydrogen sulfide
Hanford	Hanford Site
HEPA	high-efficiency particulate air
HI	hazard index
hour/km	hours per kilometer
HQ	DOE Headquarters
HRCQ	highway route-controlled quantities
ICC	Interstate Commerce Commission
ICRP	International Commission on Radiological Protection
IDB	Integrated Data Base
IDLH	immediately dangerous to life or health
IMPLAN	IMpact analysis for PLANing
INEEL	Idaho National Engineering and Environmental Laboratory
IRIS	Integrated Risk Information System
ISC3	Industrial Source Complex computer code
ISCLT3	Industrial Source Complex long-term model

ISCST3	Industrial Source Complex short-term model
kg	kilogram
kg/m^3	kilograms per cubic meter
Knolls	Knolls Atomic Power Laboratory
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LCF	latent cancer fatality
LDR	Land Disposal Restrictions
LET	linear energy transfer
LLNL	Lawrence Livermore National Laboratory
LWA	Waste Isolation Pilot Plant Land Withdrawal Act
m^3	cubic meters
MAP	Mitigation Action Plan
MB	marker bed
MEI	maximally exposed individual
mg	milligram
mg/m^3	milligrams per cubic meter
MgO	magnesium oxide
mg/s	milligrams per second
mi	mile
ml	milliliter
Mound	Mound Plant
MOU	Memorandum of Understanding
mph	miles per hour
MRA	modular risk analysis
mrem	millirem
mrem/hr	millirem per hour
MSHA	Mining Safety and Health Administration
m/s	meters per second
MWIR95	Mixed Waste Inventory Summary Report 1995
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Sciences
NCRP	National Council on Radiation Protection and Measurements
NEFTRAN	Network Flow and Transport
NEPA	National Environmental Policy Act
NERP	National Environmental Research Park
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NIOSH	National Institute of Occupational Safety and Health
NM	New Mexico
NMDG&F	New Mexico Department of Game and Fish
NMDOL	New Mexico Department of Labor
NMED	New Mexico Environment Department
NMEMNR	New Mexico Energy, Minerals, and Natural Resources Department
NO_2	nitrogen dioxide
NOA	Notice of Availability
NOI	Notice of Intent
NO_x	Oxides of nitrogen
NPDES	National Pollutant Discharge Elimination System
NRC	U.S. Nuclear Regulatory Commission

NRHP	National Register of Historic Places
NSC	National Safety Council
NTS	Nevada Test Site
NUTS	Nuclide Transport System
O_3	ozone
O&M	operations and maintenance
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OSHA	Occupational Safety and Health Administration
Pa	Pascal
Pantex	Pantex Plant
Pb	lead
PCB	polychlorinated biphenyl
pCi	picocurie
PE-Ci	plutonium-239 equivalent curies
PEIS	Programmatic Environmental Impact Statement
PEL	permissible exposure limit
PGDP	Paducah Gaseous Diffusion Plant
PIC	Passive Institutional Controls
PM_{10}	particulate matter less than or equal to 10 micrometers in diameter
PNNL	Pacific Northwest National Laboratory
ppb	parts per billion
PPE	personal protective equipment
ppm	parts per million
ppmv	parts per million volume
PSD	prevention of significant deterioration
RBP	Radiological Baseline Program
RC	retrieval and characterization
RCRA	Resource Conservation and Recovery Act
RfD	reference dose levels
RFETS	Rocky Flats Environmental Technology Site
RH-72B	remote-handled transuranic waste shipping container (proposed)
RH-TRU	remote-handled transuranic
ROD	Record of Decision
ROI	region of influence
RSPA	Research and Special Programs Administration
SAR	Safety Analysis Report
SEIS-I	Final Supplement Environmental Impact Statement for the Waste Isolation Pilot Plant
SEIS-II	Waste Isolation Pilot Plant Disposal Phase Supplemental Environmental Impact Statement
s/m^3	seconds per cubic meter
s/mg	seconds per milligram
SIC	Standard Industrial Classification
SMC	Salado Mass Concrete
SNL	Sandia National Laboratories
SNL-CA	Sandia National Laboratories, California
SNM	special nuclear material
SO_2	sulfur dioxide

SO_x	oxides of sulfur
SPM	Systems Prioritization Methodology
SRS	Savannah River Site
STEL	short-term exposure limit
SVOC	semivolatile organic compound
SWB	standard waste box
SWIFT II	Sandia Waste Isolation Flow and Transport (computer software)
TBE	Teledyne Brown Engineering
TCC	TRANSCOM Control Center
TCLP	Toxicity Characteristic Leaching Procedure
TDEM	time-domain electromagnetic
TDOP	Ten Drum Overpack
TDS	total dissolved solids
TEDE	total effective dose equivalent
TI	transportation index
TRANSCOM	Transportation Tracking and Communications System
TRC	total recordable case
TRU	transuranic
TRUCON	TRUPACT Content Codes
TRUPACT-II	Transuranic package transporter - II
TSCA	Toxic Substance Control Act
TSP	total suspended particulates
TWA	time-weighted average
UDF	unit dose factor
UEF	unit exposure factor
UIF	unit impact factor
U of Mo	University of Missouri
USAMC	U.S. Army Materiel Command
USC	United States Code
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VOC	volatile organic compound
VR	volume ratio
W	watts
WAC	planning-basis Waste Acceptance Criteria
WAC-4	Waste Acceptance Criteria, revision 4
WAC-5	Waste Acceptance Criteria, revision 5
WGA	Western Governors Association
WHB	Waste Handling Building
WIPP	Waste Isolation Pilot Plant
WM PEIS	Final Waste Management Programmatic Environmental Impact Statement
WVDP	West Valley Demonstration Project
$\overline{X}/Q'$	atmospheric dispersion factor for chronic releases

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MEASUREMENTS AND CONVERSIONS

The following information is provided to assist the reader in understanding certain concepts in this supplemental environmental impact statement (SEIS-II). Definitions of technical terms can be found in the Glossary.

EXPONENTIAL NOTATION

Exponential notation is used in SEIS-II to express very large or very small numbers. For example, the number 1 billion could be written as 1,000,000,000 or, using exponential notation, as 1E + 9. Translating from exponential notation to a more traditional number requires moving the decimal point either right (for a positive number after the E) or left (for a negative number after the E). If the value given is 5.0E + 2, move the decimal point two places (insert zeros if no numbers are given) to the right of its present location. The result would be 500. If the value given is 5.0E-4, move the decimal point four places to the left of its present location. The result would be .0005.

ROUNDING

Some numbers in SEIS-II have been rounded, therefore sums and products throughout the document may not be consistent. A number was rounded only after all calculations using that number had been made. Numbers that are actual measurements were not rounded.

The waste volumes were rounded in the following manner:

124,756.2	rounded to	125,000
61,423.7	rounded to	61,000
1,476.4	rounded to	1,500
242.4	rounded to	240
16.7	rounded to	17
8.5	rounded to	9
0.3	rounded to	1

The total waste volumes for the proposed action were not rounded because these volumes were established by the Waste Isolation Pilot Plant Land Withdrawal Act.

UNITS OF MEASURMENT

The primary units of measurement used in this report are metric units with English equivalents enclosed in parentheses. DOE Order 5900.2A, " Use of the Metric System of Measurement," prescribes the use of this system in DOE documents. Table MC-1 lists the mathematical values or formulas needed for conversion between metric and English units. Table MC-2 summarizes and defines the terms for units of measure and corresponding symbols found throughout this report.

Table MC-1
Metric Conversion Chart

To Convert to Metric			To Convert out of Metric		
If You Know	**Multiply By**	**To Get**	**If You Know**	**Multiply By**	**To Get**
Length					
inches	2.54	centimeters	centimeters	0.3937	inches
feet	30.48	centimeters	centimeters	0.0328	feet
feet	0.3048	meters	meters	3.281	feet
yards	0.9144	meters	meters	1.0936	yards
miles	1.60934	kilometers	kilometers	0.6214	miles
Area					
square inches	6.4516	square centimeters	square centimeters	0.155	square inches
square feet	0.092903	square meters	square meters	10.7639	square feet
square yards	0.8361	square meters	square meters	1.196	square yards
acres	0.40469	hectares	hectares	2.471	acres
square miles	2.58999	square kilometers	square kilometers	0.3861	square miles
Volume					
fluid ounces	29.574	milliliters	milliliters	0.0338	fluid ounces
gallons	3.7854	liters	liters	0.26417	gallons
gallons	0.00378	cubic meters	cubic meters	264.55	gallons
cubic feet	0.028317	cubic meters	cubic meters	35.315	cubic feet
cubic yards	0.76455	cubic meters	cubic meters	1.038	cubic yards
Weight					
ounces	28.3495	grams	grams	0.03527	ounces
pounds	0.45360	kilograms	kilograms	2.2046	pounds
short tons	0.90718	metric tons	metric tons	1.1023	short tons
Temperature					
Fahrenheit	Subtract 32 then multiply by 5/9ths	Celsius	Celsius	Multiply by 9/5ths then add 32	Fahrenheit
Force					
pounds per square inch	6,895	pascals	pascals	0.000145	pounds per square inch

Table MC-2
Names and Symbols for Units of Measure

Length	
Symbol	Name
cm	centimeter
ft	foot
in	inch
km	kilometer
m	meter
mi	mile
mm	millimeter
µm	micrometer

Numerical Relationships	
Symbol	Meaning
<	less than
≤	less than or equal to
>	greater than
≥	greater than or equal to
2σ	two standard deviations

Volumes and Concentrations

Symbol	Name
cm^3	cubic centimeter
ft^3	cubic foot
gal	gallon
in^3	cubic inches
L	liter
m^3	cubic meter
mL	milliliter
ppb	parts per billion
ppm	parts per million
yd^3	cubic yard

Rate

Symbol	Name
m^3/s	cubic meters per second
ft^3/s	cubic feet per second
ft^3/min	cubic feet per minute
gpm	gallons per minute
km/h	kilometers per hour
mi/h	miles per hour

Sound

Symbol	Name
dB	decibel
dBA	A-weighted decibel

Area

Symbol	Name
ac	acre
cm^2	square centimeter
ft^2	square foot
ha	hectare
in^2	square inch
km^2	square kilometer
mi^2	square mile

Mass

Symbol	Name
g	gram
kg	kilogram
mg	milligram
µg	microgram
ng	nanogram
lb	pound
ton	metric ton (1E + 6 g)

Temperature

Symbol	Name
°C	degrees Centigrade
°F	degrees Fahrenheit
°K	degrees Kelvin

Many metric measurements presented include prefixes that denote a multiplication factor that is applied to the base standard (e.g., 1 kilometer = 1,000 meters). Table MC-3 presents these metric prefixes.

Table MC-3
Metric Prefixes

Prefix	Symbol	Multiplication Factor
exa	E	1 000 000 000 000 000 000 = 10^{18}
peta	P	1 000 000 000 000 000 = 10^{15}
tera	T	1 000 000 000 000 = 10^{12}
giga	G	1 000 000 000 = 10^{9}
mega	M	1 000 000 = 10^{6}
kilo	k	1 000 = 10^{3}
hecto	h	100 = 10^{2}
deka	da	10 = 10^{1}
deci	d	0.1 = 10^{-1}
centi	c	0.01 = 10^{-2}
milli	m	0.001 = 10^{-3}
micro	µ	0.000 001 = 10^{-6}
nano	n	0.000 000 001 = 10^{-9}
pico	p	0.000 000 000 001 = 10^{-12}
femto	f	0.000 000 000 000 001 = 10^{-15}
atto	a	0.000 000 000 000 000 001 = 10^{-18}

RADIOACTIVITY UNITS

Sections of SEIS-II deal with levels of radioactivity that might be found in various environmental media. Radioactivity is a property; the amount of a radioactive material is usually expressed as "activity" in curies (Ci) (Table MC-4). The curie is the basic unit used to describe the amount of substance present, and concentrations are generally expressed in terms of curies per unit mass or volume. One curie is equivalent to 37 billion disintegrations per second or is a quantity of any radionuclide that decays at the rate of 37 billion disintegrations per second. Disintegrations generally include emissions of alpha or beta particles, gamma radiation, or combinations of both.

RADIATION DOSE UNITS

The amount of ionizing radiation energy received by a living organism is expressed in terms of radiation dose. Radiation dose in this report is usually written in terms of effective dose equivalent and reported numerically in units of rem (Table MC-5). Rem is a term that relates ionizing radiation and biological effect or risk. A dose of 1 millirem (0.001 rem) has a biological effect similar to the dose received from about a 1-day exposure to natural background radiation. A list of the radionuclides discussed in this document and their half-lives is included in the section entitled Select Radionuclides.

CHEMICAL ELEMENTS

A list of chemical elements, chemical constituents, and their nomenclature is presented in Table MC-6.

Table MC-4
Names and Symbols for Units of Radioactivity

Radioactivity	
Symbol	Name
Ci	curie
cpm	counts per minute
mCi	millicurie (1E-3 Ci)
µCi	microcurie (1E-6 Ci)
nCi	nanocurie (1E-9 Ci)
pCi	picocurie (1E-12 Ci)

Table MC-5
Names and Symbols for Units of Radiation Dose

Radiation Dose	
Symbol	Name
mrad	millirad (1E-3 rad)
mrem	millirem (1E-3 rem)

Table MC-6
Elemental and Chemical Constituent Nomenclature

Symbol	Constituents	Symbol	Constituents
Ag	silver	Pa	protactinium
Al	aluminum	Pb	lead
B	boron	Pu	plutonium
Be	beryllium	SF_6	sulfur hexafluoride
CO	carbon monoxide	Si	silicon
CO_2	carbon dioxide	SO_2	sulfur dioxide
Cu	copper	Ta	tantalum
F^-	fluoride	Th	thorium
Fe	iron	Ti	titanium
MgO	magnesium oxide	U	uranium
N	nitrogen	UO_2	uranium oxide
Ni	nickel	V	vanadium
NO_2-	nitrite	W	tungsten
NO_3-	nitrate	Zn	zinc

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HALF-LIVES OF SELECT RADIONUCLIDES

Symbol	Radionuclide	Half-Life
Ac-225	Actinium-225	10.0 days
Ac-227	Actinium-227	21.8 years
Ac-228	Actinium-228	6.13 hours
Ag-109m	Silver-109m	39.8 seconds
Am-241	Americium-241	432 years
Am-243	Americium-243	7,380 years
At-217	Astatine-217	32 milliseconds
Ba-137m	Barium-137m	2.55 minutes
B-7	Boron-7	53.4 days
Bi-210	Bismuth-210	5.01 days
Bi-212	Bismuth-212	60.6 minutes
Bi-213	Bismuth-213	46 minutes
Bi-214	Bismuth-214	19.8 minutes
Bk-249	Berkelium-249	311 days
C-14	Carbon-14	5,730 years
Cd-109	Cadmium-109	453 days
Ce-144	Cerium-144	284 days
Cf-249	Californium-249	352 years
Cf-252	Californium-252	2.64 years
Cm-242	Curium-242	163 days
Cm-243	Curium-243	28.5 years
Cm-244	Curium-244	18.1 years
Cm-245	Curium-245	8,500 years
Cm-246	Curium-246	4,730 years
Cm-247	Curium-247	1.56E + 7 years
Cm-248	Curium-248	3.39 E + 5 years
Co-60	Cobalt-60	5.27 years
Cs-134	Cesium-134	2.06 years
Cs-137	Cesium-137	30.0 years
Eu-152	Europium-152	13.33 years
Eu-154	Europium-154	8.8 years
Eu-155	Europium-155	4.96 years
Fr-221	Francium-221	4.8 minutes
H-3	Hydrogen-3	12.4 years
I-129	Iodine-129	1.57E + 7 years
Kr-85	Krypton-85	10.7 years
Ni-63	Nickel-63	96 years
Np-237	Neptunium-237	2.14E + 6 years
Np-239	Neptunium-239	2.35 days
Pa-231	Protactinium-231	3.28E + 4 years
Pa-233	Protactinium-233	27.0 days
Pa-234m	Protactinium-234m	1.17 minutes
Pb-209	Lead-209	3.25 hours
Pb-210	Lead-210	22.3 years
Pb-212	Lead-212	10.6 hours
Pb-214	Lead-214	26.8 minutes
Pm-147	Promethium-147	2.62 years
Po-210	Polonium-210	138 days
Po-212	Polonium-212	0.305 microseconds
Po-213	Polonium-213	4.2 microseconds
Po-214	Polonium-214	164 microseconds
Po-216	Polonium-216	0.15 microseconds
Po-218	Polonium-218	3.05 minutes
Pr-144	Praseodymium-144	17.3 minutes
Pu-236	Plutonium-236	2.85 years
Pu-238	Plutonium-238	87.7 years
Pu-239	Plutonium-239	24,065 years
Pu-240	Plutonium-240	6,537 years
Pu-241	Plutonium-241	14.4 years
Pu-242	Plutonium-242	3.76E + 5 years
Pu-244	Plutonium-244	8.26E + 7 years
Ra-223	Radium-223	11.4 days
Ra-226	Radium-226	1,600 years
Ra-228	Radium-228	5.75 years
Rn-220	Radon-220	55.6 seconds
Rn-222	Radon-222	3.82 days
Ru-106	Ruthenium-106	368 days
Sb-125	Antimony-125	2.77 years
Sm-151	Samarium-151	90 years
Sr-90	Strontium-90	29.1years
Tc-99	Technetium-99	2.13E + 5 years
Th-228	Thorium-228	1.91 years
Th-230	Thorium-230	7.7E + 4 years
Th-232	Thorium-232	1.41E + 10 years
U-232	Uranium-232	72 years
U-233	Uranium-233	1.59E + 5 years
U-234	Uranium-234	2.45E + 5 years
U-235	Uranium-235	7.04E + 8 years
U-236	Uranium-236	2.34E + 7 years
U-238	Uranium-238	4.47E + 9 years
Y-90	Yttrium-90	64.0 hours
Zr-95	Zirconium-95	64.0 days

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CHAPTER 1
INTRODUCTION

This chapter presents the underlying purpose and need for action, the National Environmental Policy Act (NEPA) compliance history for the Waste Isolation Pilot Plant (WIPP), the need for the second supplemental environmental impact statement (SEIS-II), the relationship of SEIS-II to other planning documents, and a description of the contents of this document.

1.1 PURPOSE AND NEED FOR ACTION

The U.S. Department of Energy (DOE or the Department) needs to dispose of transuranic (TRU) waste generated by past, present, and future activities in a manner that protects public health and the environment. In previous NEPA documents, the Department examined alternatives to repository disposal at WIPP. In this document, the Department assesses whether and, if so, how to dispose of TRU waste at WIPP.

1.2 OVERVIEW

TRU waste has been generated since the 1940s as part of the nuclear defense research and production activities of the federal government. Several types of operations (current, past, or future) have generated or will generate TRU waste: (1) nuclear weapons development and manufacturing, (2) plutonium recovery, stabilization, and management, (3) research and development, (4) environmental restoration, and decontamination and decommissioning, (5) waste management, and (6) testing at private institutions and universities under DOE contract.

Until about 1970, TRU waste, then classified as low-level waste, was disposed of in shallow trenches without an intent to retrieve it. In 1970, it was determined that TRU waste should be isolated and disposed of in a different manner than low-level waste. Thus, the Atomic Energy Commission, a DOE predecessor agency, adopted a policy

TRANSURANIC WASTE

TRU waste is defined as "waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, per gram of waste, with half-lives greater than 20 years, except for (A) high-level radioactive waste, (B) waste that the Secretary has determined, with concurrence of the Administrator, does not need the degree of isolation required by the disposal regulations; or (C) waste that the Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with part 61 of title 10, Code of Federal Regulations" (WIPP Land Withdrawal Act, Public Law 102-579).

TRU elements, each having several isotopes, are radioactive and typically man-made. The half-lives of many are considerably longer than 20 years. For instance, the half-life of one isotope of plutonium is 24,000 years.

TRU waste is further classified as contact-handled (CH) TRU waste or remote-handled (RH) TRU waste. CH-TRU waste has radioactivity levels that are low enough to permit workers to directly handle the containers in which the waste is kept. This level of radioactivity is specified as a dose rate of no more than 200 millirems per hour (mrem/hr) at the outside surface of the container. RH-TRU waste has a surface dose rate greater than 200 mrem/hr, so workers use remote manipulators to handle containers of RH-TRU waste. TRU mixed waste is CH-TRU or RH-TRU waste that also contains hazardous materials, such as lead or organic solvents regulated by the Resource Conservation and Recovery Act (RCRA).

HIGHLIGHTS OF CHANGES SINCE PUBLICATION OF THE DRAFT SEIS-II

In response to stakeholder comments and requests and in an effort to ensure that SEIS-II incorporates the Department's latest planning efforts, changes have been made throughout SEIS-II since its publication in draft form in November 1996. Sidebars are used throughout the document to indicate where changes have been made. No sidebars, though, are used to indicate changes to text boxes, figures, or tables. Below is a list of some notable modifications:

- Two sites have been removed from the tables and the maps presented throughout the document. These two sites, the Pantex Site and Teledyne Brown Engineering, have moved the small amount (less than 1 cubic meter) of TRU waste reported in the Draft SEIS-II to Los Alamos National Laboratory and Rocky Flats Environmental Technology Site, respectively. Since they no longer have TRU waste, the impacts from the waste originating at these two sites are included in the impacts for Los Alamos National Laboratory and Rocky Flats Environmental Technology Site.

- Additional text boxes have been added to Chapter 3 and Chapter 5 that discuss the impacts of waste not disposed of in WIPP under the Proposed Action. Also, additional text has been added to Chapter 3 and Chapter 5 that discusses methods of reducing the period of disposal operations for each Action Alternative to 75 years or less and how impacts would change should DOE choose to use those methods.

- The Proposed Action has been identified as DOE's Preferred Alternative, although rail transportation would continue to be an option for future transportation of TRU waste.

- Additional discussions of current socioeconomic conditions and of WIPP site geology and hydrology have been added to Chapter 4.

- All references to planning documents and to related NEPA documents have been updated. New documents have been reviewed and changes to SEIS-II have been made as needed to ensure consistency with other planning efforts.

- A new appendix (Appendix J) has been added to discuss updated TRU waste inventory estimates and current TRU waste management initiatives.

- The analyses presented in Chapter 5 and in the appendices have been reviewed, redone as necessary, and their presentation revised, based on stakeholder comments on the draft. (See the summary of comments and changes in the Summary text box titled "Issued Raised During the SEIS-II Public Comment Period.")

- Performance assessment analyses have been redone based on stakeholder comments and requests. Two particular changes should be noted. First, new analyses indicate that in this document's most conservative scenarios, radionuclides and heavy metals would reach the Culebra Dolomite should a drilling intrusion occur. Second, the performance assessment results for No Action Alternative 2 have been reduced from 2,325 fatalities to 800 fatalities during 10,000 years. Neither number, though, takes into account potential deaths due to inadvertent intrusion. Chapter 5 now includes estimates of the impacts of intrusion.

- Volume III, the *Comment Response Document*, has been added to SEIS-II. Nearly 4,000 comments were received on the Draft SEIS-II. Those comments are summarized and responses to those comments are presented in the *Comment Response Document*.

requiring that TRU waste be placed in containers and stored in a manner so as to be retrievable from storage within 20 years. The most recent estimates of TRU waste are presented in *The National Transuranic Waste Management Plan* (DOE 1996h). According to *The National Transuranic Waste Management Plan*, approximately 102,025 cubic meters (3.6 million cubic feet) of defense CH-TRU waste and 1,941 cubic meters (69,000 cubic feet) of defense RH-TRU waste are in retrievable storage at waste sites around the country. Defense TRU waste is TRU waste that has been generated due to defense activities.

In addition to the currently stored TRU waste, defense CH-TRU and RH-TRU waste would continue to be generated through the year 2033 from continuing site activities, waste management activities, and decontamination and decommissioning of DOE facilities. The most current estimate for newly generated CH-TRU waste is 38,437 cubic meters (1.4 million cubic feet) and for newly generated RH-TRU waste is 2,816 cubic meters (100,000 cubic feet). These estimates are less than previous estimates, mainly due to changes when decommissioning and decontamination activities may occur. (See Appendix J for additional discussion of *The National Transuranic Waste Management Plan* volumes.)

LAND WITHDRAWAL ACT (LWA) LIMITS

The LWA limits the amount and types of TRU waste that can be emplaced at WIPP. The limits include the following:

- WIPP capacity is limited to 175,600 cubic meters (6.2 million cubic feet) total TRU waste by volume.
- No more than 5 percent by volume of RH-TRU waste may have a surface dose rate in excess of 100 rem per hour.
- No RH-TRU waste may have a surface dose rate in excess of 1,000 rem per hour.
- RH-TRU waste containers shall not exceed 23 curies per liter maximum activity level averaged over the volume of the container.
- The total curies of RH-TRU waste shall not exceed 5,100,000 curies.

In addition the Consultation and Cooperation Agreement (C&C Agreement) with the State of New Mexico limits the volume of RH-TRU waste to 7,080 cubic meters (250,000 cubic feet).

To conservatively estimate potential impacts, analyses in SEIS-II are based on the larger total volumes in the earlier *Transuranic Waste Baseline Inventory Report, Revision 3* (BIR-3) (DOE 1996e), which incorporates the waste volumes of its second revision (BIR-2) (DOE 1995j), although analyses based on *The National Transuranic Waste Management Plan* are also included (see Appendix J and Section 5.13). The SEIS-II estimates, based on BIR-3, include 62,000 cubic meters (2.2 million cubic feet) of stored defense CH-TRU waste and 3,600 cubic meters (127,000 cubic feet) of stored defense RH-TRU waste. SEIS-II estimates also include 73,000 cubic meters (2.6 million cubic feet) of newly generated defense CH-TRU waste and 32,000 cubic meters (1.1 million cubic feet) of newly generated defense RH-TRU waste that will be generated through 2033.

DOE estimates that approximately 138,000 cubic meters (4.9 million cubic feet) of CH-TRU waste and 3,100 cubic meters (108,000 cubic feet) of RH-TRU waste was previously disposed of by near surface burial. Disposal of this buried waste at WIPP (if excavated) is also considered under SEIS-II action alternatives. Table 1-1 shows the TRU waste inventory.

Table 1-1
Current and Anticipated DOE TRU Waste (in cubic meters) [a]

Type	CH-TRU Waste	RH-TRU Waste
Stored Through 1995	62,000	3,600
Newly Generated Through 2033 [b]	73,000	32,000
PCB-Commingled	720	0
Commercial/Nondefense	200	450
Previously Disposed of Nondefense	138,000	3,100

[a] The inventory for SEIS-II is based on BIR-3 (DOE 1996e). More recent volumes are presented in Appendix J.
[b] Defense TRU waste.

Continued storage of TRU waste at the generator-storage sites poses potential problems. For example, some of the metal drums used to store TRU waste are showing signs of corrosion, and the contents of these drums eventually will have to be repackaged. Additional storage facilities would be needed at the generator-storage sites. Additional worker exposures to penetrating radiation would occur due to repackaging and inspection of waste containers. New treatment capacity would also be needed because much of the TRU mixed waste (which is about 60 percent of the waste volume discussed above) is subject to Resource Conservation and Recovery Act (RCRA) Land Disposal Restrictions (LDR) and cannot be placed in or on the land unless it is treated to satisfy those restrictions. However, recent amendments to the Land Withdrawal Act (LWA) allow WIPP to accept RCRA waste without meeting the restrictions. Also, continued storage at certain sites may require modification of legally binding agreements between DOE, the U.S. Environmental Protection Agency (EPA), and/or the states where the waste is located.

In recognition of the potential problems posed by continued storage of TRU waste, the Congress passed The National Security and Military Applications of Nuclear Energy Act of 1980 (Public Law 96-164) authorizing DOE to develop a research and development facility to demonstrate the safe disposal of radioactive waste that has resulted or will result from defense activities and that is exempted from regulation by the U.S. Nuclear Regulatory Commission (NRC) (i.e., defense TRU waste).

This legislation resulted in the design of a centralized repository for the disposal of TRU waste (after appropriate NEPA review—see below) known as WIPP. The site selected for the repository is located approximately 50 kilometers (30 miles) east of Carlsbad, New Mexico. In 1992, Congress confirmed the need for the disposal of TRU waste by passage of the WIPP Land Withdrawal Act (Public Law 102-579). The LWA reserved the area surrounding the WIPP site for construction, experimentation, operation, repair and maintenance, disposal, shutdown, monitoring, decommissioning, and other activities associated with WIPP. DOE is now proposing to continue the phased development of WIPP by disposing of TRU waste resulting from defense activities and programs.

1.3 WIPP NEPA COMPLIANCE HISTORY

In 1980, DOE prepared the *Final Environmental Impact Statement for the Waste Isolation Pilot Plant* (FEIS) to assess the potential environmental impacts of developing WIPP and of alternatives

for disposing of or managing defense TRU waste. The FEIS proposed a two-phased approach to the development of WIPP: (1) a site and preliminary design validation program and (2) full construction (DOE 1980).

The alternatives analyzed in the FEIS included the following:

- *Alternative 1: The No Action Alternative*. A research and development facility to demonstrate the safe disposal of TRU waste would not be developed, and post-1970 TRU waste would continue to be retrievably stored.

- *Alternative 2:* The two-phased approach to developing WIPP at its proposed site in southeastern New Mexico would be implemented.

- *Alternative 3*: TRU waste stored at Idaho National Engineering and Environmental Laboratory (INEEL) would be disposed of in the first available repository for high-level radioactive waste.

- *Alternative 4*: A decision on the site for WIPP would be delayed until at least 1984 to allow for the investigation of alternative sites.

In a Record of Decision (ROD) published by DOE on January 28, 1981 (46 Federal Register [FR] 9162), the Department selected Alternative 2, to proceed with the phased development of WIPP at the site in southeastern New Mexico. DOE designed the facility to accommodate 175,600 cubic meters (6.2 million cubic feet) of CH-TRU waste and 7,080 cubic meters (250,000 cubic feet) of RH-TRU waste. The Department concluded in the ROD that the adverse environmental impacts of the phased development of WIPP would be minor and that there would be minimal risk of any release of radioactivity to the environment.

After construction of most of the WIPP facilities, the Department prepared the *Final Supplement Environmental Impact Statement for the Waste Isolation Pilot Plant* (SEIS-I) (DOE 1990) to update the environmental record established in the FEIS.

SEIS-I evaluated the impacts of the following three alternatives:

- *Proposed Action Alternative:* A phased approach to develop WIPP would continue, as authorized by Public Law 96-164 and as modified by changes proposed in SEIS-I, by beginning an underground WIPP Test Phase.

- *No Action Alternative:* No waste would be emplaced at WIPP. Storage of TRU waste would continue at the generator-storage sites, and new storage facilities would be built.

- *Alternative Action:* Only those tests that could be performed without emplacing waste underground would be conducted until it was determined that WIPP complies with EPA standards and other regulatory requirements for the long-term protection of the environment from the disposal of TRU waste.

The SEIS-I ROD, published by DOE on June 22, 1990 (55 FR 25689), chose the Proposed Action Alternative. The 1990 ROD also committed the Department to prepare SEIS-II before the disposal phase and to provide an analysis of the long-term performance of WIPP in light of new information

obtained since 1990. The WIPP Test Phase was to have involved the testing of TRU waste underground at WIPP. In October 1993, DOE decided not to conduct the Test Phase. DOE decided that the experiments could be adequately performed at a lower cost in aboveground laboratories as part of the ongoing experimental program.

The 1990 ROD also stated that a more detailed analysis of the impacts of processing and handling TRU waste at the generator-storage facilities would be conducted. The Department has analyzed TRU waste management activities in the *Final Waste Management Programmatic Environmental Impact Statement* (WM PEIS) (DOE 1997b). The WM PEIS analyzes environmental impacts at the potential locations of treatment and storage sites for TRU waste; SEIS-II addresses impacts associated with alternative treatment methods, the disposal of TRU waste at WIPP and alternatives to that disposal, and the transportation to WIPP. (SEIS-II also includes potential transportation between generator sites.) Figure 1-1 shows the locations of facilities that currently store or will generate TRU waste during the 35-year period analyzed in SEIS-II.

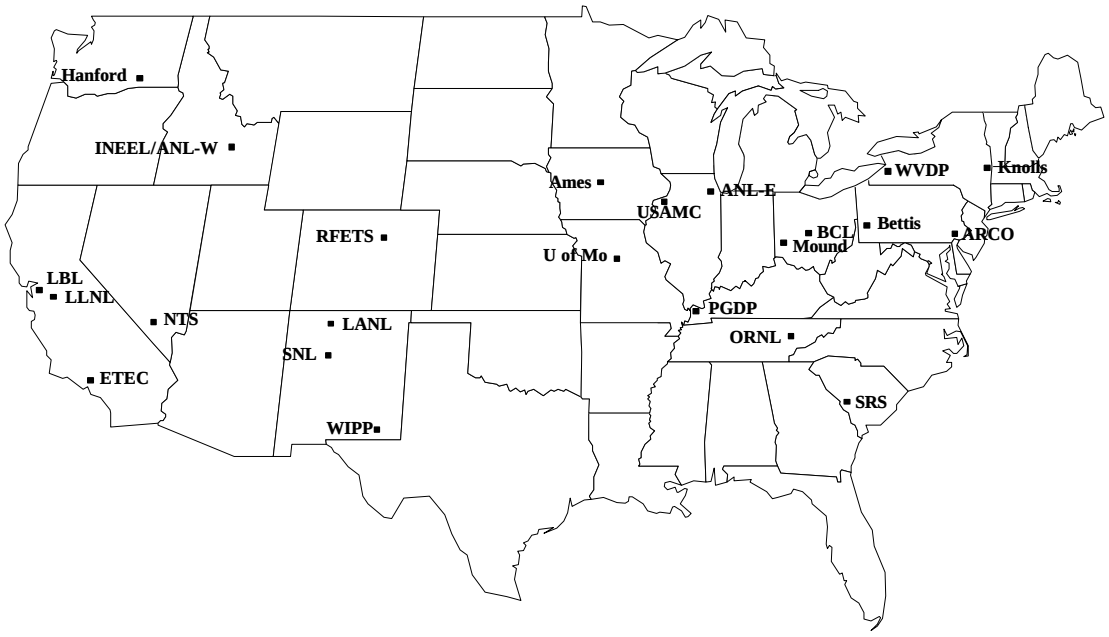


Figure 1-1
Approximate Location of SEIS-II TRU Waste [a]

[a] Although Pantex currently has no TRU waste, future decisions by the Department may result in TRU waste generation at Pantex.

Since SEIS-I, DOE has published three environmental assessments (EA) and two supplement analyses related to WIPP. These documents are summarized in Table 1-2. The Department also published a mitigation action plan (MAP) on July 10, 1991 (DOE 1991) for actions to prevent or reduce the environmental impacts associated with DOE's selected alternative. DOE issues an annual report on the progress made in implementing the MAP and the effectiveness of any mitigation and will continue to do so until the mitigation activity is complete. The report is issued annually on the anniversary date of the MAP. DOE has issued the WIPP Annual Mitigation Reports each year since the MAP was published (DOE 1992, 1993, 1994, 1995c, 1996f, and 1997d).

Table 1-2
WIPP NEPA Documents Since SEIS-I

Document Title	Document Description
Environmental Assessment for the Proposed Actinide Source-Term Test Program at Los Alamos National Laboratory (1995) (DOE/EA-0977)	This EA examined the site-specific environmental impacts of conducting tests at Los Alamos National Laboratory as part of the WIPP experimental program. A finding of no significant impact (FONSI) was issued on January 23, 1995.
Environmental Assessment for the Construction and Operation of the Carlsbad Environmental Monitoring and Research Center (1995) (DOE/EA-1801)	This EA examined the impacts of construction by New Mexico State University and continued Department funding of the operations of the Carlsbad Environmental Monitoring and Research Center. The center independently monitors environmental impacts for ongoing and future WIPP operations as part of its aim to improve environmental monitoring techniques. A FONSI was issued on October 10, 1995.
Environmental Assessment for the Construction and Operation of the Sand Dunes to Ochoa Powerline Project (1995) (DOE/EA-1109)	This EA examined the impacts of constructing a second powerline to supply electricity to WIPP. The Department adopted the Bureau of Land Management's EA and FONSI on May 19, 1995.
Supplement Analysis of Proposed Waste Characterization and Packaging Activities at the Idaho National Engineering Laboratory for the WIPP Test Program (1991) (DOE/EIS-0026-FS/SA1)	This supplement analysis described the environmental impacts of conducting some of the WIPP waste characterization activities at two locations at Idaho National Engineering and Environmental Laboratory, rather than at one location as described in SEIS-I. The activities analyzed included (1) certification and storage of CH-TRU waste at the existing Radioactive Waste Management Complex, (2) characterization and repackaging of these wastes into bins or 55-gallon drums at the existing Hot Fuel Examination Facility, and (3) transportation of wastes along the 26-mile route between the two facilities. The Department determined that these activities did not involve any substantial changes to the SEIS-I Proposed Action or notable new circumstances or information bearing on the environmental impacts, and no further NEPA documentation was required.
Supplement Analysis of Proposed Transportation Routes to the Waste Isolation Pilot Plant and Discovery of Deviated Gas Well at WIPP (1991) (DOE/EIS-0026-FS/SA2)	This supplement analysis described the selection of some TRU waste transportation routes and the discovery of a deviated gas well at WIPP. The analysis also described a directionally drilled or deviated gas well on Section 31 that was drilled in 1982. The Department determined that these activities did not involve substantial changes to the SEIS-I Proposed Action or notable new circumstances or information bearing on the environmental impacts. Therefore, DOE decided that no additional NEPA documentation was required.

1.4 NEED FOR A SECOND SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT

In addition to the Department's 1990 ROD commitment to prepare SEIS-II, regulatory and statutory changes and changes in the TRU waste inventory and waste acceptance criteria have occurred since the SEIS-I was issued. Also, new hydrologic and geologic information is available that may affect the performance assessment of WIPP and its ability to isolate waste. SEIS-II, therefore, takes into account all of the changed circumstances since 1990 that might affect the potential environmental impacts from the WIPP disposal and closure phases. Some of these changes are presented below.

- *Identification of Additional TRU Waste Generator Sites*. SEIS-I identified 10 principal generator-storage sites which have over 99 percent of the TRU waste volume that would be sent to WIPP. In the WM PEIS, the Department identified 10 additional sites that generate and store small amounts of TRU waste that may be disposed of at WIPP. Recent waste volume surveys have identified two other sites that store small quantities of TRU waste that were not identified in the WM PEIS.

- *Changes in TRU Waste Volumes and Waste Forms*. Estimates of the volumes of TRU waste and the final waste forms have changed since 1990. The volume changes are due to the reduction of activities associated with the production of nuclear weapons in the United States and better estimates of waste volumes obtained from the generator-storage sites. The changes in expected final waste forms reflect plans of certain generator-storage sites to treat their TRU waste in a manner that would alter its current form.

- *Changes in Compliance Status of Previously Disposed of TRU Waste*. Until about 1970, DOE disposed of TRU waste in shallow trenches. SEIS-I did not consider this waste in its analyses. Since SEIS-I, it has become evident that compliance with RCRA or the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) may require excavation of a portion of this previously disposed of TRU waste. If excavated, this waste would be considered newly generated. In SEIS-II, an estimate of the previously disposed of inventory is included and analyzed as part of the action alternatives.

- *Passage of the LWA*. The LWA, which transferred the WIPP site from the U.S. Department of the Interior to DOE, included provisions that might affect the environmental impacts of some WIPP disposal alternatives. As an example, one section of the Act allows no more than 175,600 cubic meters (6.2 million cubic feet) of total TRU waste volume and 5.1 million curies of RH-TRU waste to be disposed of at WIPP. Other parts of the Act require studies of rail and truck transportation, RH-TRU waste, and waste processing and volume reduction technologies. In 1996, Congress passed the National Defense Authorization Act for Fiscal Year 1997 (Public Law 104-201), which amended the LWA. Among other things, Public Law 104-201 provides the RCRA land disposal restrictions do not apply to WIPP.

- *Acquisition of New Data from the Experimental Program*. Since 1990, the Department has continued the experimental program and has acquired additional information about the WIPP site, TRU waste, and the potential interactions that may occur between the two. The results of this continuing program include new data that may more clearly define environmental impacts from WIPP. For example, there are reduced uncertainties about the rate and magnitude of gas generation from TRU waste, which bears on the long-term ability of the repository to isolate waste from the environment.

- *Carlsbad Area Office/Waste Isolation Pilot Plant Waste Minimization and Pollution Prevention Awareness Program Plan* (DOE 1995b). In 1995, DOE published this plan, which calls for a 10 percent reduction in the amount of sanitary waste generated by using source reduction techniques and a further 15 percent reduction by implementing improved recycling activities, a 30 percent reduction in the amount of RCRA-regulated waste, and the conduct of pollution prevention assessments to identify opportunities for further improvements.

- *Publication of the WM PEIS (May 1997)*. The Department has prepared a nationwide study examining the environmental impacts of managing five types of DOE radioactive and hazardous waste, including TRU waste. This study provides information on the potential impacts of various siting alternatives, which DOE will use in deciding where to locate treatment, storage, and/or, depending on the type of waste, disposal facilities. For TRU waste, the Department would identify DOE sites for treatment and storage facilities but not the type of treatment to be performed. The WM PEIS presents new information on TRU waste management. There are some differences in the waste inventories and generator-storage sites discussed in the WM PEIS and in SEIS-II. The differences are due in part to the different time periods analyzed in the WM PEIS and SEIS-II. The differences, and the reasons for them, are explained in Appendix B.

- *Changes to the Planning-Basis Waste Acceptance Criteria (WAC)*. The Department has revised the allowable activity for CH-TRU waste that could be placed in WIPP. The maximum plutonium-239 equivalent activity (PE-Ci) for untreated CH-TRU waste is 80 PE-Ci for a drum and 130 PE-Ci for a standard waste box. If overpacked in standard waste boxes or ten-drum overpacks, untreated CH-TRU waste in 55-gallon drums may contain up to 1,800 PE-Ci of activity. Drums containing solidified or vitrified CH-TRU waste, though, may contain up to 1,800 PE-Ci of activity per drum without overpacking (DOE 1996c).

- *Changes to the Transportation Routes*. Changes have been made to the planned transportation routes presented in SEIS-I.

- *Changes to the TRUPACT-II Certificate of Compliance (NRC 1989)*. NRC has modified the Certificate of Compliance (No. 9218, Revision No. 6). These changes included the addition of tritium-contaminated waste as authorized contents and the revision of generic quality assurance activities. These changes do not affect the ability of the package to meet the requirements of Title 10, Code of Federal Regulations (CFR), Part 71.

- *Changes in the Status of Relevant Regulations*. In 1993, EPA issued the Environmental Standards for Management and Disposal of TRU Waste codified in 40 CFR Part 191 and in 1996 issued criteria to certify and determine WIPP's compliance with these standards to be codified in 40 CFR Part 194 (61 FR 5224, February 9, 1996).

1.5 THE RELATIONSHIP OF SEIS-II TO OTHER DOE PLANNING DOCUMENTS

The NEPA process is a part of DOE's planning process. Council on Environmental Quality (CEQ) regulations encourage integrating environmental impact statements (EIS) "with other planning at the earliest possible time to insure that planning and decisions reflect environmental values" (40 CFR Part 1501.2). SEIS-II has been timed to take advantage of information presented in prior documents and to inform current and future planning efforts. The relationship among major planning and compliance documents and SEIS-II is as follows:

- *Compliance Certification Application (DOE 1996i):* This document, prepared in accordance with 40 CFR Part 194 and submitted to the EPA in October 1996 and accepted by the EPA in May 1997, is required by the LWA to demonstrate compliance with standards for disposal of TRU waste (40 CFR 191, Subparts B and C). Conceptual models and computer codes used for performance assessment calculations in the Compliance

Certification Application (CCA) were used in SEIS-II to assess the long-term ability of WIPP to isolate radioactive waste from the accessible environment.

- *Resource Conservation and Recovery Act Part B Permit Application (DOE 1996a):* This document, submitted April 1996, is the application to operate WIPP as a disposal facility, as defined under RCRA regulations (40 CFR Part 264). The application has been submitted to the New Mexico Environment Department, the state agency responsible for issuing the permit. (The New Mexico Hazardous Waste Act and its implementing regulations are the state analog to RCRA.). The application provides background information regarding the DOE proposals for operating WIPP and is, therefore, one of the foundations on which assumptions in SEIS-II concerning WIPP operations are based.

- *Final No-Migration Variance Petition (DOE 1996d):* This document, submitted to the EPA and published on June 14, 1996, is a petition to receive a variance from the RCRA LDRs on the basis that the migration of hazardous constituents would not exceed health-based levels at the disposal unit boundary. However, such a variance is no longer required pursuant to the National Defense Authorization Act for Fiscal Year 1997, Public Law No. 104-201. The document also provides background information on the long-term ability of WIPP to isolate hazardous waste and has been summarized and incorporated by referenced throughout SEIS-II.

- *Waste Isolation Pilot Plant Safely Analysis Report (SAR), Revision 0 (DOE 1995i):* The intent of this document, published in November 1995, is to examine the hazards associated with the disposal of CH-TRU and RH-TRU waste and to identify where mitigation is needed. The SAR provides accident analyses of CH-TRU and RH-TRU waste. These analyses have been incorporated into SEIS-II where appropriate.

- *Waste Isolation Pilot Plant Safety Analysis Report (SAR), Revision 1, (DOE 1997a):* As with Revision 0, the intent of this document, published in March 1997, is to examine the hazards associated with the disposal of CH-TRU waste and to identify where mitigation is needed. The SAR provides accident analyses of CH-TRU waste (similar analyses for RH-TRU waste are not included). These analyses have been incorporated into SEIS-II, where appropriate.

- *Transuranic Waste Baseline Inventory Report, Revision 2 (BIR-2) (DOE 1995j):* This report, published in December 1995, provides the waste volumes, hazardous constituent inventories, and most of the radionuclide data used by DOE in its regulatory compliance applications. BIR-2 (as well as BIR-3, below) is used as the basis for the SEIS-II waste volumes. SEIS-II supplements the radionuclide inventory with inventory data from the Integrated Data Base (IDB) (DOE 1995e).

- *Transuranic Waste Baseline Inventory Report, Revision 3 (BIR-3) (DOE 1996e):* This report, which DOE used for the WIPP CCA, includes information pertaining to waste that is currently eligible for disposal at WIPP under existing laws. BIR-3 waste volumes and hazardous constituent inventories are unchanged from BIR-2. The radionuclide inventories at some sites are changed. Also, information on complexing agents, nitrates, sulfates, phosphates, and cement was added because these components could potentially affect WIPP's ability to contain TRU waste. The information on complexing agents, nitrates, sulfates, phosphates, and cement was incorporated into the parameters used in the SEIS-II

analysis of long-term performance. The adjusted volumes used for SEIS-II analyses are based upon BIR-3 inventories.

- *Remote-Handled Transuranic System Assessment (DOE 1995h):* This report, published in November 1995, discusses the disposal of DOE RH-TRU waste. The report discusses packaging RH-TRU waste at treatment sites in such a way that it could be handled as CH-TRU waste. This would entail placing the RH-TRU waste in shielded payload containers to limit the radiation dose at the outer container surface to not more than 200 mrem/hr. This waste could then be handled and emplaced as CH-TRU waste. All other CH-TRU waste requirements would apply as well. This study also considered several options for RH-TRU waste emplacement, such as putting the waste in repository walls, in vertical boreholes in the floors of the repository, or in trenches mined in the repository floor. These considerations were used to determine the number of repository panels needed under the Proposed Action and the action alternatives in SEIS-II.

- *Remote-Handled Transuranic Waste Study (DOE 1995f):* This study was conducted, as required by the LWA, to evaluate the impacts of RH-TRU waste on the performance assessment of the repository and to determine the effects of RH-TRU waste as a part of the WIPP Total Inventory. Also, this study conducted a comparison of CH-TRU and RH-TRU waste to assess differences and similarities for gas generation, flammability and explosiveness, solubility, and brine and geotechnical interactions. The conclusions and findings of this study were considered when addressing TRU waste handling and performance assessment concerns in SEIS-II.

- *The National Transuranic Waste Management Plan (DOE 1996h):* This plan, published in September 1996, presents a TRU waste management system for the DOE Complex. The system maintains compliance with all binding consent orders, unilateral orders, and regulatory agreements concerning TRU waste and creates a management system in support of the DOE Office of Environmental Management's *Accelerating Cleanup: Focus on 2006* (DOE 1997c). (New TRU waste volume estimates presented in this plan are discussed in Appendix J and Section 5.13.)

Based on these documents, DOE believes it has sufficient information to meaningfully evaluate the environmental impacts of the proposal to dispose of TRU waste at WIPP and of the alternatives to that proposal.

In addition, several DOE NEPA documents that are related to SEIS-II either have been completed since SEIS-I, are being prepared, or have been proposed. As discussed below, DOE is preparing project-level, site-wide, and programmatic NEPA documents that address TRU waste management facilities or potential TRU waste generating activities throughout the DOE complex. These parallel efforts are being undertaken to expedite compliance with site-specific consent orders and settlements and to meet DOE's responsibilities under NEPA. The decisions that may result from these NEPA reviews may change the amount of TRU waste at DOE facilities. The amount of waste used for SEIS-II quantitative analyses does not reflect these possible decisions. The potential volume changes, though, are expected to be small relative to the total amount of waste considered for the SEIS-II calculations.

Final Waste Management Programmatic Environmental Impact Statement (Published in 1997, [DOE 1997b])

The relationship between SEIS-II and the WM PEIS (DOE 1997b) is set forth in Appendix B of this document. SEIS-II uses the WM PEIS to support its analyses in two principal ways. First, it uses the WM PEIS results as a baseline, updates that information, and adjusts the impacts according to differences in the concentration of radionuclides and differences in waste volume from the addition of buried waste. Second, SEIS-II alternatives use the locations of proposed treatment facilities presented in the WM PEIS (DOE 1997b).

The WM PEIS preferred alternative assumes that TRU waste would be treated to planning-basis WAC at the facilities where it is currently stored or would be generated, except that waste at the Pantex Plant and Sandia National Laboratories (SNL) would be shipped to Los Alamos National Laboratory (LANL) for treatment, Rocky Flats Environmental Technology Site (RFETS) would send a portion of its TRU waste to INEEL for treatment, Savannah River Site (SRS) would send its RH-TRU waste to Oak Ridge Reservation for treatment, and the Oak Ridge Reservation would send its CH-TRU waste to SRS for treatment.

Although SEIS-II incorporates by reference and, where appropriate, updates and adjusts information from the WM PEIS, the potential actions analyzed in SEIS-II are not connected to the potential actions analyzed in the WM PEIS. To further explain, the WM PEIS evaluates alternative configurations for managing (treating, storing, or disposing of) five types of waste, including TRU waste, that are at DOE sites or are otherwise under DOE's control or responsibility. The alternative configurations range from managing the wastes where they are currently located to transporting them to one centralized site for management. The WM PEIS evaluates trends in various impacts as alternative configurations become more or less centralized. The WM PEIS postulates three generic types of treatment for TRU waste, in order to analyze the impacts of treating and storing TRU waste under the various alternative configurations (although the WM PEIS does not address TRU waste disposal, recognizing that a disposal decision would be made on the basis of the WIPP SEIS-II). These generic treatments allow DOE, in the WM PEIS, to compare the relative impacts of centralized, regionalized, and decentralized treatment and storage. To reduce the potential impacts of storing untreated wastes, DOE must decide, pursuant to the WM PEIS, the most cost-effective and environmentally preferable configuration to treat and store TRU waste, regardless of whether the Department decides to dispose of this waste at WIPP.

In addition to TRU waste, the WM PEIS analyzes four other types of waste: high-level waste, low-level waste, low-level mixed waste, and hazardous waste. These wastes would not be disposed of at WIPP, and management of these wastes is unrelated to, and outside the scope and purpose of, SEIS-II.

SEIS-II, in contrast, is the third in a series of staged NEPA reviews that focuses on WIPP disposal of TRU waste. SEIS-II analyzes impacts and alternatives for disposal at WIPP, transportation to WIPP, and associated activities not addressed in, and not within the scope of, the WM PEIS. SEIS-II involves additional and different workers, time frames, transportation modes, alternatives, and affected environments. Decisions associated with whether to dispose of TRU waste at WIPP can and should be made regardless of any decisions made pursuant to the WM PEIS. Furthermore, decisions for TRU waste disposal are far removed from decisions on management of the other types of waste analyzed in the WM PEIS. Decisions concerning WIPP pursuant to SEIS-II will not automatically trigger or prejudice decisions for high-level waste, low-level waste,

hazardous waste, and low-level mixed waste that may be made pursuant to the WM PEIS. As such, SEIS-II and the WM PEIS have different purposes, meet different needs, and are independently justified.[1]

Storage and Disposition of Weapons-Usable Fissile Materials Final Programmatic Environmental Impact Statement (Published in 1996, DOE/EIS-0229)

This programmatic environmental impact statement (PEIS) (DOE 1996j) analyzes alternatives for the storage and disposition of weapons-usable fissile materials that originate in the United States. Weapons-usable fissile materials are those that could be used to make nuclear weapons and include various isotopes of plutonium (except plutonium-238, which is used as an energy source for space missions) and uranium highly enriched in uranium-235. Specifically, this PEIS analyzes alternatives for the storage of surplus weapons-usable plutonium and highly enriched uranium until any disposition, the storage of nonsurplus weapons-usable plutonium and highly enriched uranium, and the disposition of surplus plutonium. Storage alternatives for plutonium and uranium include using current storage facilities (no action alternative), upgrading current facilities, consolidating plutonium storage at a new facility, and co-locating plutonium and highly enriched uranium storage at a new facility. Disposition alternatives for plutonium include several alternatives in the following categories: emplacement in a deep borehole; immobilization in glass, ceramic, or metal; and fabrication into mixed oxide fuel with subsequent burning in nuclear reactors. The Department issued its ROD on this PEIS on January 21, 1997. The Department decided to pursue a dual strategy for disposing of excess plutonium that would immobilize some (and potentially all) of the inventory in a glass or ceramic material, and allows the burning of some of the surplus plutonium as mixed oxide fuel in existing reactors, depending upon subsequent decisions. The Department is preparing a *Surplus Plutonium Disposition Environmental Impact Statement* (Notice of Intent, May 22, 1997, 62 FR 28009**)**. The disposition of surplus weapons-usable plutonium (a fissile material) could produce approximately 4,500 cubic meters (158,000 cubic feet) to 7,000 cubic meters (245,000 cubic feet) of TRU waste for disposal at WIPP. (The additional TRU waste is discussed in the Cumulative Impacts section of Chapter 5.)

Los Alamos National Laboratory Site-Wide Environmental Impact Statement (Draft in Preparation)

DOE is preparing a site-wide EIS for LANL that will include an analysis of existing and planned waste management activities, including those for TRU waste, for the next 5 to 10 years (DOE 1995g). The potential environmental consequences that would result from the implementation of existing and anticipated activities, possible mitigation measures, site-specific strategies for TRU waste management, and projects reasonably expected during this period will be addressed.

Final Environmental Impact Statement for the Nevada Test Site and Off-site Locations in the State of Nevada (Published in 1996, DOE/EIS-0243-F)

A site-wide EIS was prepared to help define the future mission of the Nevada Test Site (DOE 1996g). This site-wide EIS evaluated resource management alternatives that would support current and future defense related missions, research and development, waste management,

[1] DOE believes that the analyses presented in the WM PEIS and SEIS-II are more understandable and useful for decision making and for informing the public than they would be if combined in a single, less focused document.

environmental restoration, infrastructure maintenance, and facility upgrades and alternative uses over the next 5 to 10 years. The Department issued its ROD on this PEIS on December 13, 1996.

With respect to TRU and TRU mixed waste, the Department decided to continue onsite storage pending the development of DOE disposal decisions. The Department also decided to construct a facility for characterizing and certifying TRU waste for offsite disposal**.**

Management of Certain Plutonium Residues and Scrub Alloy Stored at the Rocky Flats Environmental Technology Site Environmental Impact Statement (Draft in Preparation)

DOE is preparing an EIS (Notice of Intent, 61 FR 58866, November 19, 1996) to decide how and where certain non-weapons-usable plutonium residues and scrub alloy, currently located at the RFETS, would be managed. DOE previously analyzed the stabilization of the approximately 106,000 kilograms (233,690 pounds) of plutonium residues at the RFETS for safe interim storage in the *Solid Residue Treatment, Repackaging, and Storage Environmental Assessment* (DOE 1996b). This EIS will analyze treatment alternatives for approximately 42,000 kilograms (92,594 pounds) of the plutonium residues and all of the scrub alloy in storage at the RFETS.

Site-Wide Environmental Impact Statement for the Rocky Flats Environmental Technology Site (Preparation Suspended)

DOE has issued a Notice of Intent (59 FR 4001, August 5, 1994) to prepare a site-wide EIS for the RFETS. The Notice described the intended scope of the site-wide EIS as providing a basis for selection of a site-wide strategic approach for nuclear materials storage, waste management, cleanup, and economic conversion, as well as project-level decisions for land use, management of nuclear materials, deactivation of RFETS facilities, decontamination and decommissioning of existing facilities, and possible on-site and off-site transportation of radioactive, hazardous, and mixed waste. The scope of the site-wide EIS has been modified so that issues associated with the safe interim storage of plutonium at RFETS will be analyzed in the Plutonium Interim Storage EIS (Notice of Intent, 61 FR 37247, July 17, 1996), and completion of the site-wide EIS has been suspended.

Savannah River Site Waste Management Final Environmental Impact Statement (Published in 1995, DOE/EIS-0217)

DOE issued the *Savannah River Site Waste Management Final Environmental Impact Statement* (DOE 1995d) that evaluates the construction and operation of low-level mixed waste and TRU mixed waste facilities identified in the *Savannah River Site Treatment Plan* developed under the Federal Facility Compliance Act (FFCAct) and the effects of minimizing, treating, storing, and disposing of liquid high-level radioactive, low-level radioactive, hazardous, mixed (radioactive and hazardous), and TRU waste. The EIS is intended to support decisions on the operation of specific treatment, storage, and disposal facilities over the next 10 years and to provide a baseline for analyses of future waste management activities. A ROD (60 FR 55249 [1995]) was issued October 30, 1995, announcing DOE's intention to implement the moderate treatment configuration alternative for storing, and treating transuranic waste, among others. The ROD also indicated that DOE will issue additional RODs pertaining to the treatment of mixed low-level radioactive and TRU mixed waste following negotiations with the State of South Carolina under the Federal Facility Compliance Act.

Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Environmental Impact Statement (Published in 1995, DOE/EIS-0203-F)

Based upon this programmatic and site-wide EIS (DOE 1995a), DOE issued an ROD on June 1, 1995 (60 FR 28680), which when implemented might result in the acceptance of off-site TRU waste from other DOE sites for treatment (pending negotiations under the FFCAct and decisions to be made based on the WM PEIS). DOE issued an amendment to the ROD on March 8, 1996 (61 FR 9441) incorporating the terms of the settlement agreement and court order in *Public Service Co. v. Batt*. The settlement agreement/court order requires shipment of INEEL TRU waste to WIPP or other such facility by a target date of December 31, 2018.

1.6 CONTENT OF SEIS-II

This SEIS-II is composed of six chapters and twelve appendices, as follows:

- *Chapter 1, Introduction:* This chapter defines the purpose and need for agency action. It also presents an overview of the WIPP project, a summary of its NEPA compliance history, and discussions of other DOE NEPA efforts and planning documents.

- *Chapter 2, Background Information:* This chapter provides an overview of DOE's TRU waste management throughout its facilities, includes details on the WIPP project and facility, presents a discussion of the TRU waste inventories, and summarizes relevant stakeholder outreach and involvement activities.

- *Chapter 3, Description of the Proposed Action and Alternatives:* This chapter is a description of the Proposed Action (Preferred Alternative) and each of the alternatives. The Proposed Action is to proceed with the phased development of WIPP by disposing of retrievably stored and future-generated defense TRU waste after treatment to the planning-basis WAC, up to the limits of the LWA and the DOE—New Mexico Agreement for Consultation and Cooperation. There are three alternatives to the Proposed Action, each involving different TRU waste treatment options and different waste volumes. There are two no action alternatives, one in which TRU waste would remain at various DOE sites in compliance with applicable regulations and another in which TRU waste would be stored at consolidation sites. WIPP would not open if either no action alternative is selected.

- *Chapter 4, Description of the Affected Environments:* This chapter summarizes and updates the description of the affected environment contained in the FEIS and SEIS-I and discusses new information regarding the hydrogeology at the WIPP site. It also summarizes the affected environment at the 10 major generator-storage sites.

- *Chapter 5, Environmental Impacts:* This chapter presents analyses of postulated radionuclide and hazardous chemical releases and exposures for the Proposed Action and action alternatives, the impacts that would result both from routine transportation and operations and from transportation and operational accidents, and the potential impacts of closing WIPP under the no action alternatives and from long-term repository performance after closure under the Proposed Action and the action alternatives. This chapter also includes discussions of environmental justice, the potential impacts of waste retrieval and recovery, cumulative impacts, and mitigation measures. Additional discussions include

unavoidable adverse impacts, i.e., those that may remain following mitigation; short-term uses of man's environment and the maintenance and enhancement of long-term productivity; and irreversible or irretrievable commitment of resources that would result from implementation of the Proposed Action.

- *Chapter 6, Consultations and Permits:* This chapter discusses the agencies and persons consulted and provides the status of compliance with key regulatory requirements.

- *Appendix A, Waste Inventory:* This appendix provides information on the characteristics and quantities of DOE TRU waste.

- *Appendix B, Summary of the Waste Management Programmatic Environmental Impact Statement and Its Use in Determining Human Health Impacts:* This appendix provides an overview of that information in the WM PEIS that is relevant to SEIS-II.

- *Appendix C, Air Quality:* This appendix describes the methods used for analyzing potential impacts to air quality at WIPP for routine emissions of nonradiological air pollutants during normal operations.

- *Appendix D, Life-Cycle Costs and Economic Impacts:* This appendix discusses the technical approach and sources of information used to estimate the life-cycle costs and economic impacts of the SEIS-II alternatives.

- *Appendix E, Transportation:* This appendix forms the basis for transportation impact analysis results and discusses plans for transporting TRU waste.

- *Appendix F, Human Health:* This appendix describes the methods used to estimate human health impacts that result from radioactive material and hazardous chemical exposures and intakes.

- *Appendix G, Facility Accidents:* This appendix describes the methods used to estimate the impacts of facility accidents, both at WIPP and at treatment, consolidation, and storage facilities.

- *Appendix H, Long-Term Consequence Analysis for Proposed Action and Action Alternatives:* This appendix describes the analytical methods, codes, and exposure calculations used to determine the impacts from postulated long-term release scenarios.

- *Appendix I, Long-Term Consequence Analysis for No Action Alternative 2:* This appendix describes the analytical methods, codes, and exposure calculations used to determine the impacts from postulated long-term release scenarios.

- *Appendix J, Changes in the Department of Energy's Transuranic Waste Management Program*: This appendix describes other DOE TRU waste inventories and waste management practices.

- *Appendix K, List of Preparers and Contributors:* This appendix provides the names and credentials of those persons involved in the preparation of SEIS-II.

- *Appendix L, Distribution List:* This appendix contains a list of the individuals that received a copy of either the full Draft SEIS-II document and/or the Summary.

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CHAPTER 2
BACKGROUND INFORMATION

This chapter provides an overview of the management of transuranic (TRU) waste throughout U.S. Department of Energy (DOE or the Department) facilities, presents details on the Waste Isolation Pilot Plant (WIPP) and its history, and concludes with a summary of stakeholder outreach and involvement activities relevant to the preparation of this second supplemental environmental impact statement (SEIS-II).

2.1 OVERVIEW OF TRU WASTE IN THE DOE COMPLEX

During the past 50 years, DOE and its predecessor agencies have been responsible for atomic energy and nuclear weapons research and production. The nuclear weapons complex has consisted of major facilities, including those at large reservations in the states of Nevada, Idaho, Washington, and South Carolina. In New Mexico and California, national laboratories have designed weapons, most of which were assembled in Texas, from components fabricated in Colorado, Florida, Missouri, Ohio, Tennessee, and Washington (DOE 1997).

TRU waste results from defense activities and programs of the U.S. government. Several types of operations (current, past, or future) have generated or will generate TRU waste: (1) nuclear weapons development and manufacturing; (2) plutonium recovery, stabilization, and management; (3) research and development; (4) environmental restoration, and decontamination and decommissioning; (5) waste management at various DOE and other government facilities and laboratories; and (6) testing at private institutions and universities under contract to DOE. TRU waste also results from commercial activities subject to regulation by the U.S. Nuclear Regulatory Commission (NRC) and from DOE-sponsored activities that are not considered to be defense activities or programs.

KEY DEFINITIONS

Defense TRU Waste: TRU waste that results from defense activities. Since 1970, this waste has been placed in retrievable storage. It continues to be generated from environmental restoration, decontamination and decommissioning activities, waste management programs, and testing and research.

Nondefense TRU Waste: TRU waste that currently is restricted from disposal in WIPP by the WIPP Land Withdrawal Act (LWA) because it does not result from defense activities.

Commercial TRU Waste: TRU waste produced by commercial facilities licensed by the U.S. Nuclear Regulatory Commission (NRC) and restricted from disposal in WIPP because it does not result from defense activities. DOE is managing some of this waste at the direction of Congress.

Polychlorinated Biphenyl (PCB)-Commingled TRU Waste: TRU waste that contains 50 parts per million or greater of PCBs and is subject to regulation under the Toxic Substances Control Act (TSCA). This waste is currently restricted from disposal in WIPP unless treated in compliance with the TSCA or unless WIPP receives a permit to dispose of TRU waste under the TSCA.

Previously Disposed of Waste: TRU waste that, prior to 1970, was disposed of in shallow burial pits, and that, if excavated, would be considered newly generated waste, potentially eligible for disposal in WIPP.

WASTE ACCEPTANCE CRITERIA (WAC)

The WAC was first developed in 1989 and revised several times, most recently in 1996. These criteria govern the form, packaging, and transport of TRU waste to be disposed of at WIPP, should WIPP disposal be approved. These criteria also address WIPP operations and safety requirements, transportation requirements, waste package requirements, Resource Conservation and Recovery Act (RCRA) requirements, and performance assessment requirements. Overall, they consolidate the minimum requirements of all laws, regulations, and DOE internal requirements that apply to TRU waste transportation and disposal and establish specific minimum waste characteristics which TRU waste must meet before it can be accepted and emplaced at WIPP.

The WAC establish the conditions that govern the physical, radiological, and chemical composition for TRU waste, setting weight, thermal, and radiological limits. Weight limits are established for TRUPACT-II containers, contact-handled (CH) TRU waste drums, and shipments so that shipments will not exceed highway weight limits. Thermal power limits, which define the amount of heat that may be produced by radioactive decay, are established for waste containers to limit the concentration of flammable gas which may be generated within the container. Radiological criteria include the maximum plutonium-239 equivalent activity (PE-Ci) for containers and for stored TRU waste to avoid the potential for nuclear criticality.

For the purposes of SEIS-II analyses, all waste would be packaged at a minimum to the current planning-basis WAC. In addition, the alternatives examine more extensive treatment by a shred and grout or thermal process. Even if treated by a shred and grout or thermal process, though, all waste must necessarily also meet the minimum criteria embodied in the WAC to be disposed of at WIPP. Also, to be transported for consolidation or treatment, TRU waste must meet minimum WAC requirements, which include transportation requirements.

The version of the WAC used for the SEIS-II analyses was Revision 5 (DOE 1996b), the most current planning-basis WAC. As laws and regulation change, and should new waste criteria be developed as a result of SEIS-II, the WAC will be revised to reflect the new requirements.

2.1.1 Introduction

For the purposes of SEIS-II, TRU waste is broadly categorized to include (1) defense waste of the type that was subject to previous WIPP-related National Environmental Policy Act (NEPA) reviews and (2) other defense and nondefense waste for which DOE retains management responsibility. The *Final Environmental Impact Statement for the Waste Isolation Pilot Plant* (FEIS) (DOE 1980) and *Final Supplement Environmental Impact Statement for the Waste Isolation Pilot Plant* (SEIS-I) (DOE 1990) examined the impacts of transporting and disposing of waste that resulted from defense activities and that was placed in retrievable storage pursuant to a 1970 Atomic Energy Commission policy (see Section 1.2) and TRU waste that was reasonably expected to be generated by these ongoing activities and programs. For the purposes of SEIS-II, this defense TRU waste inventory is hereafter referred to as the "Basic Inventory."

Other defense and nondefense TRU waste not previously included in the waste inventory by the FEIS or SEIS-I include (1) nondefense and commercial TRU waste (comprising 0.2 percent of the total TRU waste volume), (2) defense TRU waste commingled with PCBs, (3) and defense (and perhaps some nondefense) TRU waste disposed of prior to the Atomic Energy Commission policy of 1970. This TRU waste inventory is hereafter referred to as the "Additional Inventory."

In addition, SEIS-II refers to the "Total Inventory," which is the sum of the Basic and Additional Inventories.

Previously disposed of TRU waste excavated in compliance with RCRA, the Comprehensive Environmental Response, Compensation, and Liability Act, or as a result of DOE's own cleanup initiatives would be considered newly generated waste and as such could become potentially eligible for WIPP disposal.

2.1.2 TRU Waste

TRU waste contains transuranic radionuclides and may also contain other radionuclides. Most TRU radionuclides decay through the emission of alpha radiation. However, transuranic and other radionuclides present in the waste may emit beta, gamma, X-ray, and neutron radiation as well. Alpha (helium nuclei) and beta (electron) radiation are particulate emissions that cannot penetrate the walls of TRU waste containers and present a health hazard only if the particles are inhaled or ingested. Gamma (photon), X-ray (electromagnetic), and neutron (uncharged particle) radiation can penetrate the walls of waste containers and may present an external dose hazard to individuals near the containers. Gamma and X-ray radiation can be shielded to reduce the radiation dose to workers using high density materials such as lead or steel; neutrons must be shielded using materials with high hydrogen content such as water, plastic, or paraffin. Radionuclides americium-241, an X-ray emitter, barium-137m, a gamma-emitter that is a decay product of cesium-137, and cobalt-60, another gamma-emitter, are the main contributors to external dose from TRU waste that would be disposed of at WIPP under the Proposed Action and the action alternatives.

TRU waste is categorized as either CH-TRU or remote-handled (RH) TRU based on the external dose rates at the surface of the waste container. TRU waste is considered CH-TRU waste if the external dose rate at the outer surface of the waste container is 200 millirem per hour or less. TRU

TRU WASTE TRANSPORTATION PACKAGING

The Department plans to use two packagings to transport TRU waste; a third is under consideration.

***TRUPACT-II*:** The TRUPACT-II would be used to transport CH-TRU waste. The NRC has certified these containers. To achieve NRC approval, these containers must endure fire, water immersion, and free drops without leakage. Each container has the capacity to hold fourteen 55-gallon drums, two standard (0.9-meter x 1.4-meter x 1.8-meter [3.1-foot x 4.5-foot x 5.9-foot]) waste boxes, or a 10-drum overpack which fits one standard waste box or ten 55-gallon drums. Each TRUPACT-II has an allowable capacity of 2,835 kilograms (6,250 pounds). Up to three TRUPACT-IIs can be transported on a specially designed trailer, and up to six containers can be carried on a specially adapted rail car.

RH-72B: The RH-72B cask would be used to transport RH-TRU waste. The Department is currently awaiting NRC certification of the RH-72B cask. This package is designed to shield personnel and the environment from penetrating radiation that is produced by RH-TRU waste. The canister within each cask can hold up to 3,630 kilograms (8,000 pounds). One RH-72B cask can be carried on a specially designed trailer, and up to three casks can be carried on a specially adapted rail car.

HALFPACK: The HALFPACK is being developed by the Department and is a shorter, lighter version of the TRUPACT-II. It would allow the shipment of waste containers too heavy to be shipped efficiently in a TRUPACT-II because of U.S. Department of Transportation weight limitation requirements. The HALFPACK would hold half the volume of waste as the TRUPACT-II.

waste with an external dose rate greater than 200 millirem per hour is considered RH-TRU waste; however, RH-TRU waste with an external dose rate greater than 1,000 rem per hour (1,000,000 millirem per hour) at the outer surface of the container cannot be disposed of at WIPP because it is prohibited by the LWA.

DOE has developed a coding system, comprised of waste matrix code groups, to organize waste streams by their physical and chemical properties. Eleven waste matrix code groups for waste having similar physical and chemical properties have been used to categorize CH-TRU waste and RH-TRU waste (DOE 1996c). These code groups are listed in Table 2-1.

TRU mixed waste is defined as any TRU waste that is commingled with a hazardous waste regulated by RCRA, as defined in Title 40, Code of Federal Regulations (CFR) 261, Subparts C and D. TRU waste containing hazardous chemical constituents has physical and radiological characteristics similar to TRU waste that does not contain these constituents. The majority of TRU mixed waste contains relatively small quantities of spent halogenated solvents, which were used in

Table 2-1
Final TRU Waste Form Code Groups and Definitions

Final TRU Waste Form Code Group	Definition
Combustible	Debris that is approximately 95 percent or more, by volume, combustible materials. Examples of combustible debris are materials constructed of plastic, rubber, wood, paper, and cloth.
Filter	Debris that is approximately 50 percent or more, by volume, High Efficiency Particulate Air (HEPA) filters or additional filters constructed of more than one material type (e.g., metal, inorganic nonmetal, and combustibles).
Graphite	Debris that is approximately 95 percent or more, by volume, graphite-based solid materials. Graphite debris includes crucibles, graphite components, and pure graphite.
Heterogeneous	Debris that is at least 50 percent by volume materials that do not meet criteria for assignment into other categories. For example, waste that is a mixture of metal and combustible debris, neither of which comprises 95 percent or more of the waste by volume.
Inorganic nonmetal	Debris that is approximately 95 percent or more, by volume, inorganic nonmetal material. Examples of waste in this group include glass and ceramics.
Lead/cadmium metal	Debris that is approximately 95 percent or more, by volume, metal that contains bulk lead or cadmium as part of the matrix. Examples of this waste include glovebox parts with lead clad in stainless-steel or cadmium sheets.
Uncategorized metal	Debris that is approximately 95 percent or more, by volume, metal but either lacks sufficient information to enable characterization into one of the other categories or contains both lead and cadmium as part of the bulk matrix.
Salt	Debris that is at least 50 percent by volume salts. Stable pyrochemical salt is an example of this group.
Soil	Debris that is approximately 95 percent or more, by volume, soil. This includes sand, silt, and rock/gravel where rock/gravel volumes total less than 50 percent of the matrix.
Solidified inorganic	Debris that is at least 50 percent by volume inorganic process residues. This group includes solidified sludges and small particles.
Solidified organic	Debris that is at least 50 percent by volume organic process residues. These are defined as process residues with a base structure that is primarily organic. The matrix may contain some inorganic solids content such that approximately 20 percent by weight of the waste would remain as residue ash/solids following incineration. Examples include organic resins, organic sludges and solidified organic liquids.

cleaning and degreasing of equipment, glassware, and components. Based on sampling of gases within TRU waste drums, the most common volatile organic hazardous constituents are methylene chloride, carbon tetrachloride, and 1,1,1-trichloroethane (DOE 1996c). TRU mixed waste also contains various RCRA-regulated metals. These metals are usually associated with solid materials, such as lead shielding and chromium-based stainless steel. Lead, chromium, and cadmium are the most prevalent heavy metals in TRU mixed waste. TRU mixed waste is approximately 60 percent of the Department's TRU waste.

For the TRU waste that would be disposed of at WIPP, DOE has created the planning-basis WAC (DOE 1996b). These criteria specify all of the requirements that must be met by each waste generator-storage site before its TRU waste is shipped to WIPP and disposed of and govern the physical, radiological, and chemical composition of the waste, as well as requirements for waste packaging. Criteria have been developed for shipping, packaging, waste form, waste package, data package, and other miscellaneous criterion categories. These criteria address WIPP operations and safety, transportation, waste package requirements, RCRA requirements, and WIPP performance assessment requirements.

For example, some of the criteria under the waste package requirements include the following:

- The maximum gross weight of the TRUPACT-II with payload is 8,730 kilograms (19,250 pounds) and the maximum gross weight of the canister of the RH-72B cask is 3,630 kilograms (8,000 pounds).

- Total gross weight of a transporter including payload is 36,300 kilograms (80,000 pounds).

- The maximum plutonium-239 equivalent activity (expressed as PE-Ci) for untreated TRU waste is 80 PE-Ci for a drum or 130 PE-Ci for a standard waste box. If overpacked in standard waste boxes or 10-drum overpacks, untreated CH-TRU waste in 55-gallon drums may contain up to 1,800 PE-Ci of activity. Drums containing solidified or vitrified CH-TRU waste may contain up to 1,800 PE-Ci of activity per drum. RH-TRU waste canisters may not exceed 1,000 PE-Ci (DOE 1996b).

- Liquid waste cannot exceed 2 liters (0.5 gallons) in a CH-TRU waste drum, 8 liters (2 gallons) in a standard waste box, or 6 liters (1.5 gallons) in a RH-TRU waste canister.

- The maximum removable surface contamination on drums is 50 picocuries (pCi) per 100 square centimeters (16 square inches) for alpha-emitting radionuclides and 450 pCi per 100 square centimeters (16 square inches) for beta and gamma-emitting radionuclides.

- The maximum thermal power must be less than 40 watts for a TRUPACT-II and be less than 300 watts for a RH-TRU waste canister.

Future additions or revisions to the planning-basis WAC may be necessary; for example, additional RCRA requirements may be issued or results of the WIPP performance assessment studies may require changes. Any changes to the planning-basis WAC based on SEIS-II analyses will be identified in the Record of Decision (ROD). Section 2.2.1 and Appendix A discuss planning-basis WAC further.

2.1.3 Waste Management at the Generator-Storage Sites

The locations and volumes of the TRU waste inventory are given in Table 2-2 (for the Basic Inventory) and Table 2-3 (for the Additional Inventory).

The 1990 SEIS-I (DOE 1990) stated that WIPP may eventually dispose of post-1970 defense TRU waste from 10 sites. These sites are identified in Table 2-2. Since 1990, DOE has identified 12 additional sites that either store or are anticipated to generate TRU waste. Eight of these sites store or generate TRU waste considered to be part of the Basic Inventory (Table 2-2). TRU waste

Table 2-2
Basic Inventory TRU Waste Volumes [a, b]

	Stored (1995) (cubic meters)		Estimated Total through 2022 [c] (cubic meters)		Projected Total through 2033 [d] (cubic meters)	
Site [e]	**CH-TRU**	**RH-TRU**	**CH-TRU**	**RH-TRU**	**CH-TRU**	**RH-TRU**
Hanford Site (Hanford)	12,000	200	46,000	22,000	57,000	29,000
Los Alamos National Laboratory (LANL)	11,000	94	18,000	190	21,000	230
Idaho National Engineering and Environmental Laboratory (INEEL)	28,000	220	28,000	220	28,000	220
Argonne National Laboratory - West (ANL-W)	7	19	750	1,300	1,000	1,700
Argonne National Laboratory - East (ANL-E)	25	---	150	---	200	---
Savannah River Site (SRS)	2,900	---	9,600	---	12,000	---
Rocky Flats Environmental Technology Site (RFETS)	4,900	---	9,300	---	11,000	---
Oak Ridge National Laboratory (ORNL)	1,300	2,500	1,600	2,900	1,700	3,100
Lawrence Livermore National Laboratory (LLNL)	230	---	940	---	1,200	---
Nevada Test Site (NTS)	620	---	630	---	630	---
Mound Plant (Mound)	300	---	300	---	300	---
Bettis Atomic Power Laboratory (Bettis)	---	---	120	7	170	9
Sandia National Laboratories - Albuquerque (SNL)	7	---	14	---	17	---
Paducah Gaseous Diffusion Plant (PGDP)	---	---	6	---	8	---
U.S. Army Materiel Command (USAMC)	3	---	3	---	3	---
Energy Technology Engineering Center (ETEC)	2	6	2	7	2	7
University of Missouri Research Reactor (U of Mo)	1	---	1	---	1	---
Ames Laboratory - Iowa State University (Ames)	---	---	1	---	1	---
Battelle Columbus Laboratories (BCL)	---	580	---	580	---	580
Totals	**62,000**	**3,600**	**116,000**	**27,000**	**135,000**	**35,000**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. The thermal treatment, though, is not necessarily for PCB-commingled waste. TRU waste containing more than 50 parts per million of PCBs cannot be disposed of at WIPP without applicable permits. The Basic Inventory is waste that resulted from defense activities and that was placed in retrievable storage pursuant to the Atomic Energy Commission policy of 1970 and TRU waste reasonably expected to be generated by these ongoing activities. Volumes have been rounded. Actual totals may differ due to rounding. Projected totals have not been adjusted in anticipation of disposal. A discussion of updated volumes and TRU waste locations presented in the *National Transuranic Waste Management Plan* is presented in Appendix J, throughout SEIS-II, where appropriate, and in the Summary.

[b] Dashes indicate no waste.

[c] Post-1970 defense TRU waste volumes through 2022 are estimated in BIR-2.

[d] The Proposed Action, described in Chapter 3, is based on operation of WIPP for 35 years through 2033. Total includes TRU waste to be generated for 35 years.

[e] Sites in boldface were included in SEIS-I. INEEL and ANL-W are located near each other and are counted as a single site in SEIS-II; however, ANL-W is listed separately to indicate its contribution to the inventory.

Table 2-3
Additional Inventory TRU Waste Volumes [a, b, c]

Site [d]	PCB-Commingled (cubic meters)		Commercial/Nondefense (cubic meters)		Previously Disposed of (cubic meters)		Total (cubic meters)	
	CH-TRU	RH-TRU	CH-TRU	RH-TRU	CH-TRU	RH-TRU	CH-TRU	RH-TRU
Hanford Site (Hanford)	240	--- [e]	---	---	63,000	1,000	63,000	1,000
Los Alamos National Laboratory (LANL)	---	---	---	---	14,000	120	14,000	120
Idaho National Engineering and Environmental Laboratory (INEEL)	460	---	---	---	57,000	440	57,000	440
Savannah River Site (SRS)	---	---	---	---	4,900	---	4,900	---
Oak Ridge National Laboratory (ORNL)	---	---	5	---	61	120	66	120
Mound Plant (Mound)	19	---	---	---	---	---	19	---
Sandia National Laboratories - Albuquerque (SNL)	---	---	---	---	1	---	1	---
ARCO Medical Products Company (ARCO)	---	---	1	---	---	---	1	---
Knolls Atomic Power Laboratory (Knolls)	---	---	---	81	---	---	---	81
Lawrence Berkeley Laboratory (LBL)	---	---	2	---	---	---	2	---
West Valley Demonstration Project (WVDP)	---	---	190	370	---	1,400	190	1,700
Totals	**720**	**---**	**200**	**450**	**138,000**	**3,100**	**139,000**	**3,500**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. The thermal treatment, though, is not necessarily for PCB-commingled waste. The Additional Inventory includes PCB-commingled TRU waste, commercial TRU waste, nondefense TRU waste, and TRU waste disposed of prior to the Atomic Energy Commission policy of 1970. A discussion of updated volumes and TRU waste locations presented in the *National Transuranic Waste Management Plan* is presented in Appendix J, throughout SEIS-II, where appropriate, and in the Summary.

[b] The volume of TRU waste includes the 1995 existing and projected waste through 2033.

[c] Actual totals may differ due to rounding.

[d] Sites in boldface also store post-1970 defense TRU waste, see Table 2-2. The remaining four sites currently have no post-1970 defense TRU waste.

[e] Dashes indicate no waste.

stored at the remaining four sites (ARCO, Knolls, LBL, and WVDP) is part of the Additional Inventory (Table 2-3). Together, TRU waste at these 22 sites account for all waste analyzed as part of SEIS-II (see Figure 2-1).

Additional information about the TRU waste inventory can be found in Appendix A. The waste volumes shown in Tables 2-2 and 2-3 are based on 35 years of future projected generation beginning in 1998, plus the TRU waste in retrievable storage (see Appendix J for updated inventory information). Projections between 1995 and 1998 are included. DOE recognizes that TRU waste may continue to be generated after 2033 but believes that volume projections beyond 2033 are too speculative to be useful for the analyses at this time; however, DOE may include projections beyond 2033 in any future NEPA analyses.[1]

There is uncertainty in the total waste volume figures presented in Tables 2-2 and 2-3. The projections beyond 2022 are extrapolations based on the projected waste generation rates between 1995 and 2022 and provide bounding estimates for use in the analyses. The amount of previously disposed of TRU waste that could be retrieved for eventual storage or disposal is highly uncertain. Decisions on disposition of waste and contaminated media from environmental restoration activities are made on a cleanup-by-cleanup basis, and such decisions have not been made for many of the Department's environmental restoration activities. Also, the Department is in the process of characterizing and developing cleanup strategies for many contaminated sites and, therefore, cannot precisely determine what type or volume of waste might result from cleanup of those sites.

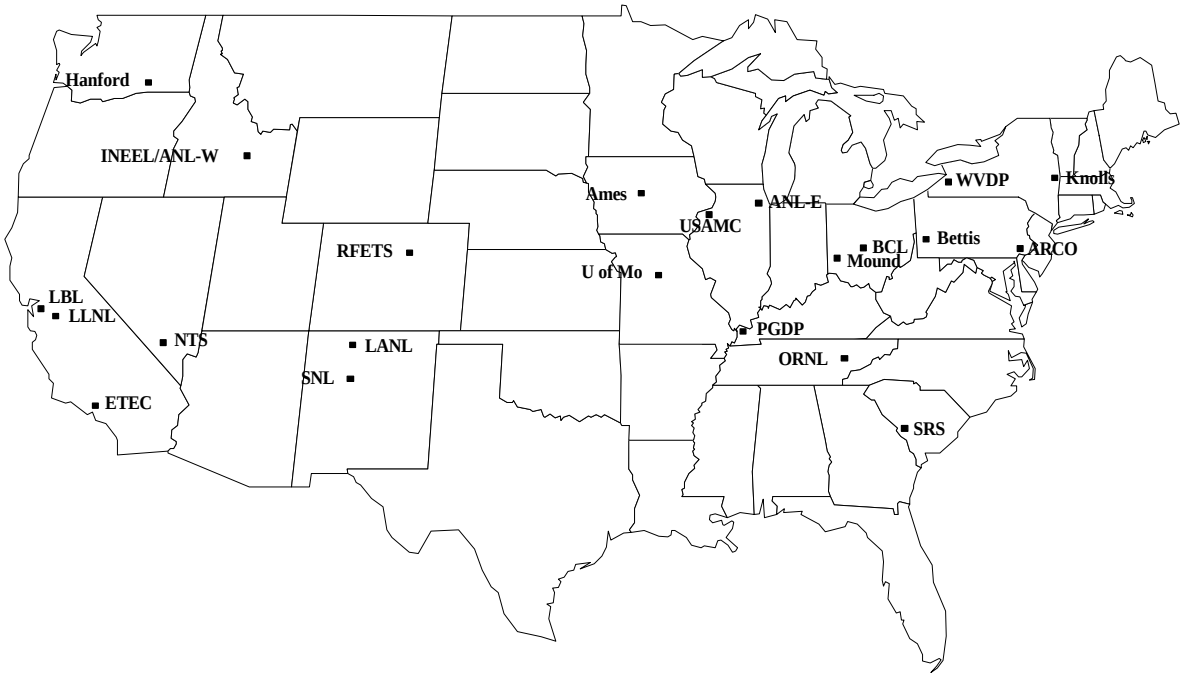


Figure 2-1
Approximate Location of SEIS-II TRU Waste [a]

[a] Although Pantex currently has no TRU waste, future decisions by the Department may result in TRU waste generation at Pantex.

[1] While SEIS-II provides an analysis of impacts based on 35 years of waste generation, the Department's current RCRA Part B Permit Application (DOE 1996a) is based on 25 years and will be renewed every 5 years.

In addition, the waste volumes used for SEIS-II analyses are estimates of "emplaced waste volumes" (the volumes of the containers that TRU wastes would be emplaced in), not actual waste volumes inside the containers, except as noted. DOE recognizes that virtually all containers would contain some void space and that some containers may be only partially filled (for instance, to meet limits on weight or thermal power for transportation).

The ROD (55 Federal Register [FR] 25689) based on SEIS-I (DOE 1990) stated that SEIS-II would examine in greater detail waste management at the generator-storage sites. Later in 1990, DOE announced its intent to prepare a programmatic environmental impact statement for managing the treatment, storage, and disposal of radioactive and hazardous waste in the DOE Complex, including the treatment and storage of TRU waste (55 FR 42633). Also, in 1992, the U.S. Congress passed the Federal Facility Compliance Act (FFCAct) requiring DOE to prepare plans for developing treatment capacities and technologies for mixed waste. The FFCAct requires the site treatment plans to be submitted to the states or the U.S. Environmental Protection Agency (EPA) for review, and authorizes the states or EPA to issue orders requiring compliance with the plans. The *Final Waste Management Programmatic Environmental Impact Statement* (WM PEIS) (DOE 1997), published in June 1997, was developed in parallel with the FFCAct site treatment plans.

To date, DOE has submitted FFCAct site treatment plans for a majority of its sites, and in most cases orders or settlements have been reached with the states and EPA. Certain orders and settlements also include schedules for transporting treated TRU waste to WIPP. DOE has reached a negotiated settlement with the State of Idaho concerning TRU waste that was entered by the court in the case of *Public Service Co. v Batt,* Civil NO 91-0035-S-EJL (D. ID, October 17, 1995). DOE intends to keep its commitments pursuant to these binding agreements and orders. The Order issued to LANL requires DOE to complete treatment of TRU mixed waste to applicable regulatory standards by December 31, 2010. By September 30, 2023, Oak Ridge National Laboratory (ORNL) must complete shipment of stabilized RH-TRU waste sludges and CH- and RH-TRU solids to WIPP. And at RFETS, newly generated TRU mixed waste cannot be stored for longer than two years once WIPP begins accepting mixed TRU waste from RFETS.

The site treatment plans reflect DOE's strategy for the management of TRU mixed waste. Most of the FFCAct agreements allow the Department to continue to store TRU mixed waste without treating it to meet the RCRA Land Disposal Restrictions (LDR), recognizing that DOE has plans to decide whether to dispose of this waste at WIPP. (Such TRU mixed waste could be disposed of at WIPP without treatment to meet the RCRA LDRs under the recent amendments to the LWA in Public Law 104-201.) The LANL FFCAct agreement is an exception to this general rule, requiring DOE to begin planning for the LDR treatment of LANL TRU mixed waste but allowing renegotiation should WIPP open. Treatment of all the TRU waste to meet the LDRs is still a reasonable alternative and is analyzed in SEIS-II.

Under any of the alternatives assessed in SEIS-II, the generator-storage sites would maintain the capability to manage TRU waste generated in the future. In general,

LEGALLY BINDING ORDERS AND AGREEMENTS

DOE is subject to a number of legally binding agreements and orders concerning TRU waste. One example of such an order is the negotiated settlement agreement entered by the court in the case of *Public Service Co. v Batt*, Civil No. 91-0035-S-EJL (D. ID, October 17, 1995). DOE intends to keep its commitments pursuant to these binding agreements and orders.

the facilities would vary by site depending on the waste streams and volumes generated and could have the capability to do the following:

- Safely store TRU waste generated from the various waste streams
- Characterize TRU waste which could involve radioassay and nondestructive testing, headspace sampling, inner-bag gas sampling, drum venting, solids sampling, real-time radiography, and visual sampling
- Treat TRU waste through size reduction, vitrification, or thermal treatment
- Certify TRU waste to meet planning-basis WAC requirements
- Package TRU waste
- Load TRU waste containers

These facilities would provide the generator-storage sites with the capability to prepare TRU waste for shipment to the major treatment sites. Treatment sites would have capabilities similar to those listed above for the generator-storage sites but would generally be sized to handle a greater volume of TRU waste.

Additional information regarding alternatives for the management of TRU waste, as studied in the WM PEIS, may be found in Appendix B.

2.1.4 Waste Isolation Pilot Plant

In 1957, the National Academy of Sciences concluded that the most promising method of disposal of high-level waste seemed to be in bedded salt deposits. Some of the most favorable characteristics of bedded salts included (1) that they were generally found in geologically stable regions that were capable of waste isolation for hundreds of millions of years, (2) that salt beds were essentially dry, with no intergranular liquids, and (3) that salt would creep and encapsulate wastes for long periods of time following disposal.

Following a study of salt beds throughout the Permian Basin, which includes the Delaware Basin in Eastern New Mexico and large areas of Kansas, West Texas, and Oklahoma, the WIPP site was selected during the early 1970s as a research and development facility to demonstrate the safe disposal of radioactive waste resulting from defense-related activities. Eastern New Mexico was specifically selected as the area for the WIPP site in early studies by ORNL (Appendix MASS, CCA [Doe 1996e]) because it best met the following criteria:

Characteristics	Requirement
Depth of Salt	1000 to 2500 feet
Thickness of Salt	at least 200 feet
Lateral Extent of Salt	Sufficient to protect against dissolution
Tectonics	Low historical seismicity, no salt-flow structures nearby

Characteristics (cont'd)	Requirement (cont'd)
Hydrology	Minimal groundwater
Mineral potential	Minimal
Existing Boreholes	Minimal number (No Deep Boreholes within two miles of the site)
Population Density	Low
Land Availability	Federal Land Preferred (Three square miles and a two-mile-wide buffer zone)

DOE's predecessor agency selected a candidate site in bedded salt beds contained within the Salado Formation northeast of the present WIPP site in 1974. However, field investigations conducted to confirm existing site information found unexpected geologic structures such as steeply dipping beds, missing units, and brine containing hydrogen sulfide near the deeper planned repository depths. This early site was deemed unacceptable and a search for a new site was initiated in late 1975 which identified the present site.

The WIPP site is located in southeastern New Mexico (Figure 2-2). The site is approximately 50 kilometers (30 miles) east of Carlsbad, New Mexico, in an area known as Los Medaños, a relatively flat, sparsely inhabited plateau with little surface water (DOE 1990). WIPP consists of the 41-square-kilometer (16-square-mile) area under the jurisdiction of DOE pursuant to LWA. The WIPP site boundary was established to ensure that at least 1.6 kilometers (1 mile) of intact salt exists laterally between the waste disposal area and the accessible environment and to ensure that no permanent residences will be established in close proximity to the facility.

WIPP includes surface and underground facilities that would support waste handling and emplacement. These facilities were discussed in Section 2.2 of SEIS-I (DOE 1990). The principal surface structure at WIPP is the Waste Handling Building (WHB) (Figure 2-3). The primary function of the WHB and its associated systems is to unload TRU waste (from the TRUPACT-II for CH-TRU waste and from the RH-72B cask, if it is NRC certified for RH-TRU waste) and to transfer the containers of TRU waste to the underground disposal area through a waste shaft. The WHB contains four functional areas: the CH-TRU waste handling area, the RH-TRU waste handling area, the WHB support area, and the waste shaft (DOE 1996c). Other surface facilities include the hoist houses, support building, guard and security building, water pump house, TRUPACT-II maintenance building, training building, office trailers, exhaust filter building, warehouse and shops, engineering building, drill core storage building, and the safety and emergency services building.

The WIPP underground facilities are located at the repository horizon 655 meters (2,150 feet) beneath the surface (Figure 2-4). These facilities include the waste disposal area, an experimental region (deactivated in 1995 and 1996), access tunnels, and associated support facilities (DOE 1996c). The underground support facilities include those needed to service and maintain equipment for excavation and disposal operations, monitor for contamination, and allow limited decontamination of personnel and equipment, if necessary. All WIPP facilities currently have protection for potential fire, tornado, lightning, high wind, and other types of natural disasters. All underground facilities also are inspected by both the Occupational Safety and Health Administration and the Mine Safety and Health Administration.

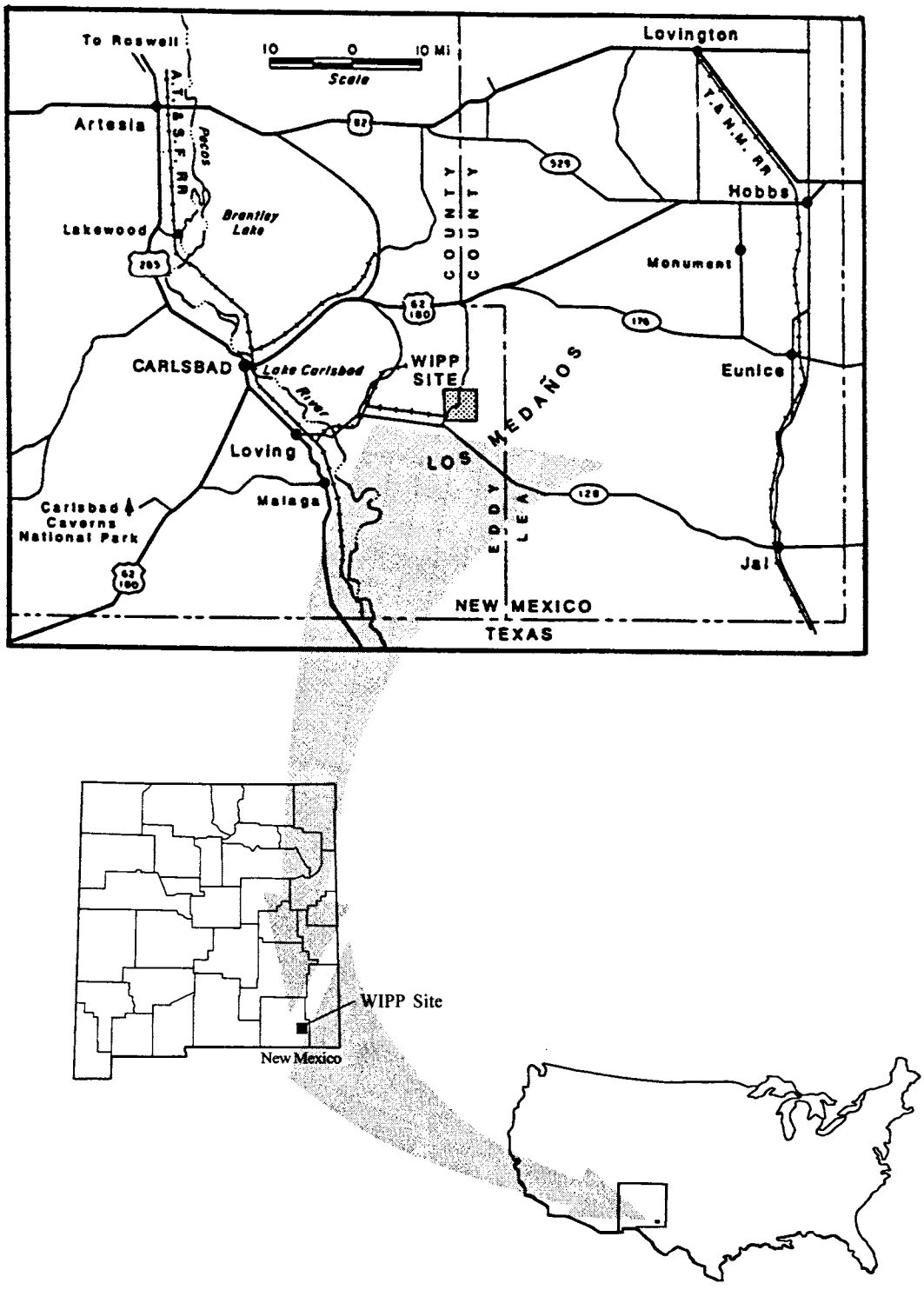
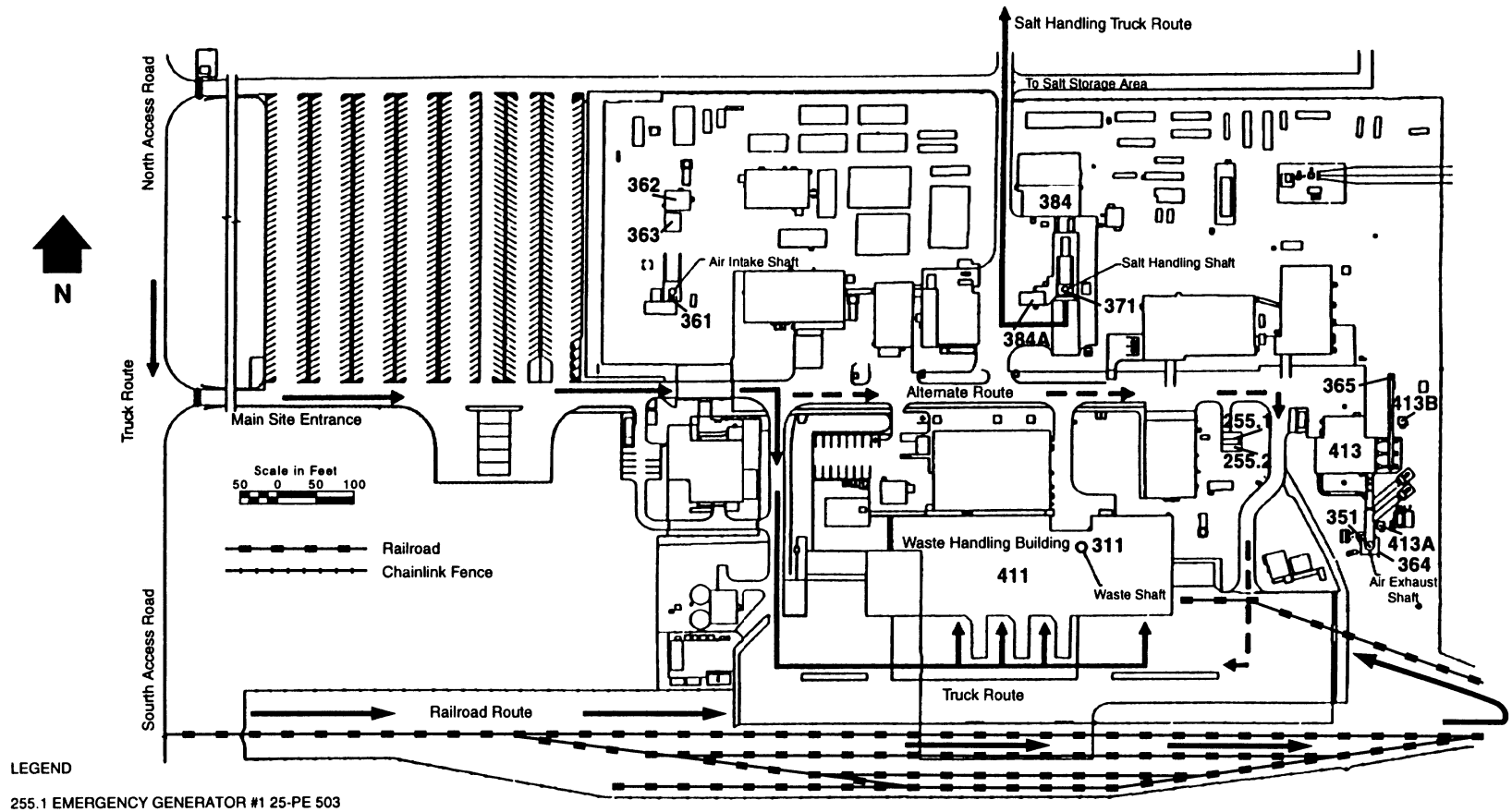


Figure 2-2
The Location of WIPP



LEGEND

255.1 EMERGENCY GENERATOR #1 25-PE 503
255.2 EMERGENCY GENERATOR #2 25-PE 504
311 WASTE SHAFT
351 EXHAUST SHAFT
361 AIR INTAKE SHAFT
362 AIR INTAKE SHAFT/HOIST HOUSE
363 AIR INTAKE SHAFT/WINCH HOUSE
364 EFFLUENT MONITORING INSTRUMENT SHED A
365 EFFLUENT MONITORING INSTRUMENT SHED B
371 SALT HANDLING SHAFT
384 SALT HANDLING SHAFT HOISTHOUSE
384A SALT HOIST OPERATIONS
411 WASTE HANDLING BUILDING
413 EXHAUST-SHAFT FILTER BUILDING
413A MONITORING STATION A
413B MONITORING STATION B

Figure 2-3
WIPP Surface Structures

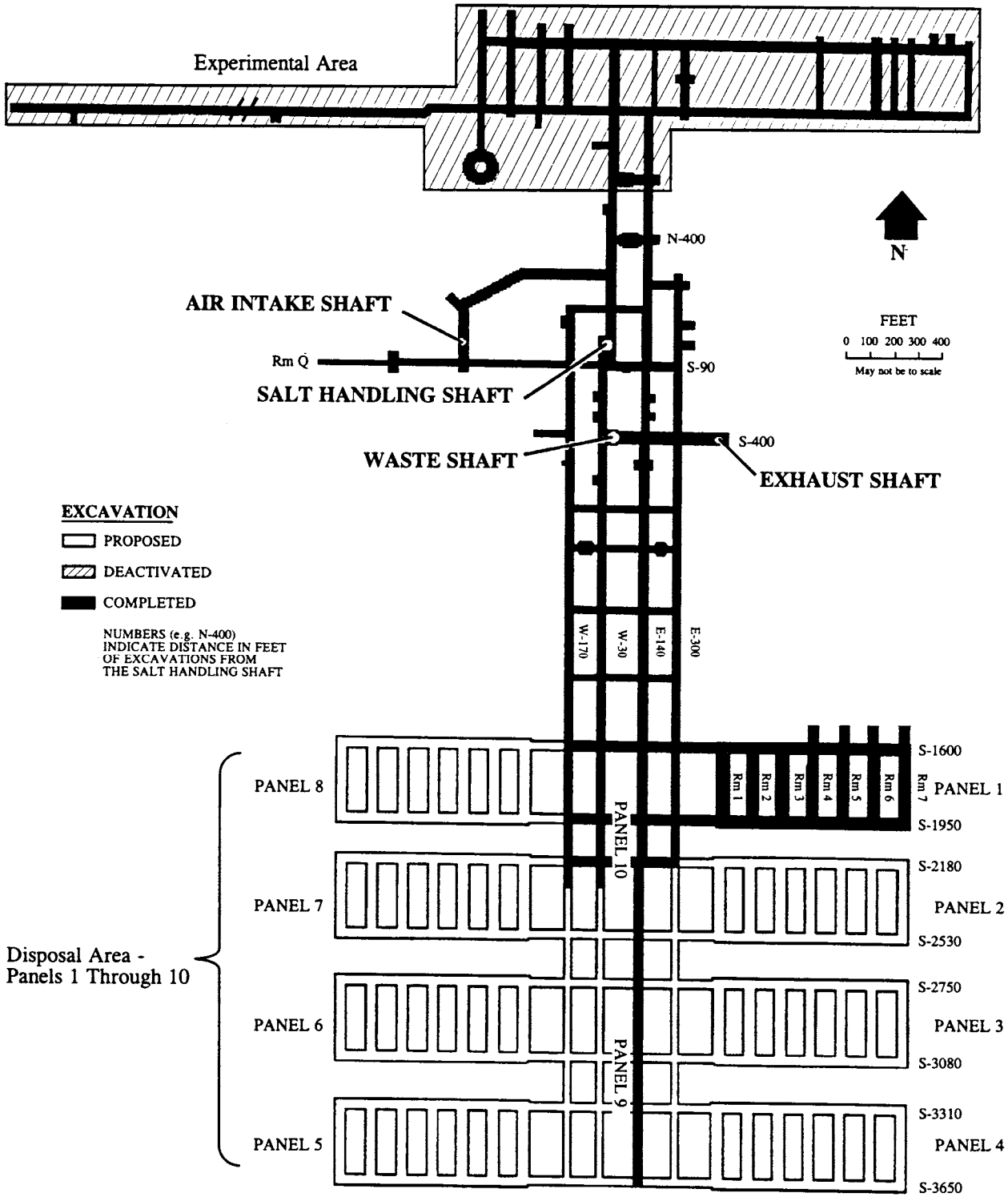


Figure 2-4
Plan View of WIPP Underground Facility
(655 meters [2,150 feet] below ground level)

One underground panel (panel 1) has been excavated. Seven additional panels and the north-south accessways (i.e., panel-equivalents 9 and 10) would be necessary to accommodate the 175,600 cubic meters (6.2 million cubic feet) of TRU waste permissible under LWA. Each panel would consist of seven waste disposal rooms, each about 91 meters (300 feet) long, 10 meters (33 feet) wide, and 4 meters (13 feet) high. Pillars between rooms would be 30 meters (100 feet) wide. Rockbolts or other types of ground control techniques would be used, as necessary, to ensure safe conditions during waste emplacement activities (DOE 1996c).

2.2 TRU WASTE TREATMENT

Although there are many different physical, chemical, and thermal treatment methods that have been previously tested or are in development for TRU waste treatment (DOE 1995c), the three types of treatment in SEIS-II are the same as those considered in the WM PEIS (DOE 1997). To ensure that the full range of potential impacts were considered, SEIS-II examined three types of treatment based on increasing levels of complexity: a minimal level of treatment needed to meet planning-basis WAC, an intermediate level of treatment using a shred and grout process, and a more complex level of thermal treatment sufficient to comply with the RCRA LDRs. DOE maintains that the impacts from these three levels of treatment represent a full range of impacts for available treatment methods.

The Proposed Action and one alternative would treat and package TRU waste only as needed to meet planning-basis WAC. A second alternative would use a shred and grout process, increasing the volume of the TRU waste by encapsulating it in cement. One alternative and one no action alternative would use a thermal treatment process to destroy organic components of the TRU waste and fuse the remainder into a glass or ceramic product, or possibly, into a metal ingot. Both CH-TRU and RH-TRU waste would be treated by the same processes; only the handling of the TRU waste would vary.

These three levels reasonably bound the potential environmental impacts for other types of treatment that might be developed for future TRU waste application. DOE will select the type of treatment necessary to satisfy disposal and storage criteria. The decisions that DOE makes on the basis of SEIS-II may be a combination of the treatment methods analyzed. This means that two or more of the treatment options may be selected for different portions of the waste.

OBJECTIVES OF TRU WASTE TREATMENT

TRU waste needs to be treated in order to put it in a form that would allow it to be safely handled, transported, and disposed of.

Treatment requirements are established to ensure compliance with requirements established by law, regulations, and DOE internal orders that are designed to protect the safety and health of workers. For example, planning-basis WAC prohibit waste containing over 50 parts per million of PCBs because land disposal of that waste would require a permit under TSCA. Other planning-basis WAC limitations, such as limitations on free liquids, are imposed because of the potential impacts of certain waste forms on the ability of WIPP to isolate the radioactive portion of the waste as required by EPA regulations (40 CFR Part 191).

Several RCRA requirements, including the prohibitions on explosives, compressed gases, and corrosive materials, are incorporated into the planning-basis WAC.

2.2.1 Treatment to Meet Planning-Basis WAC

Planning-basis WAC (DOE 1996b) defines the physical, quality assurance, handling, and documentation requirements that must be met for a container of TRU waste to be accepted at WIPP for disposal. The requirements specify TRU waste characteristics and limits and include radionuclide content, activity levels, and permissible shipping container weight. Explosives, compressed gases, and corrosive materials are prohibited by planning-basis WAC. Restrictions are set on amounts of residual liquids, thermal power, and pyrophoric materials. Planning-basis WAC includes WIPP-specific requirements as well as requirements set by various regulatory agencies, including the NRC, EPA, and U.S. Department of Transportation. Stored TRU waste may be WAC-certified or may need treatment to meet planning-basis WAC certification requirements.

Chapter 5 of this document explains how impacts would differ among alternatives if portions of the total waste volume analyzed were treated under each treatment option should the Department decide to combine two or more treatment options.

The baseline process used by treatment sites to ensure that TRU waste meets planning-basis WAC includes:

- TRU waste retrieval from storage
- TRU waste characterization in accordance with the *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995e)
- TRU waste treatment and packaging as needed to allow shipment in the TRUPACT-II or RH-72B packaging. Waste treatment might involve removing or solidifying residual liquids, neutralizing corrosive and deactivating reactive wastes, removing and puncturing compressed gas containers, solidifying particulates, and recementing stored TRU waste sludges. Waste treatment also may require the repackaging of existing TRU waste to fit into the appropriate shipping containers and the removal of items that do not conform with the WAC.
- TRU waste certification to planning-basis WAC

TRU waste characterization is an important step in determining whether the final TRU waste form meets planning-basis WAC. Depending on the TRU waste matrix code groups, characterization would include some or all of the following:

- Nondestructive, nonintrusive assay to identify and quantify the radionuclides in the TRU waste
- Radiographic analyses to determine the physical form of TRU waste in closed containers
- Container headspace gas analysis to detect the presence of hydrogen, methane, or EPA-listed volatile organic compounds
- Solids analyses for the presence of heavy metals such as lead, cadmium, or beryllium
- Visual inspection of an appropriate number of containers to verify quality control

Treatment sites would properly treat TRU waste identified as nonconforming during characterization. Treatment facilities would be designed to protect workers, the public, and the environment from exposure to radioactive and hazardous materials.

Planning-basis WAC uses thermal power limits as a surrogate for the gas generation potential of TRU waste. When TRU waste is in close proximity to organic materials, hydrogen gas can be produced, and hydrogen gas can be an explosion hazard. Thermal power limits vary according to the radiation and the packaging of the TRU waste within a container. For example, the hydrogen concentration for waste transported in a TRUPACT-II is limited to no greater than 5 percent (within the innermost layer of packaging) over a 60-day period. Because packaging CH-TRU waste in plastic bags inhibits the dispersal of the generated gas, the rate of gas dispersion decreases with increasing bag layers. Therefore, the more bag layers present in CH-TRU waste packaging, the greater the amount of gas present, the lower the allowed thermal power (DOE 1994) and thus, a smaller volume of CH-TRU waste would be allowed per waste container to limit gas generation. For the purposes of analyses in SEIS-II, it was assumed that no bags were used (bagless posting), thereby maximizing the volume of waste in a container and the concentration of waste that would be emplaced at WIPP. This assumption also would reduce the number of waste shipments.

2.2.2 Shred and Grout Treatment

In a shred and grout treatment process, TRU waste would be shredded to achieve a relatively uniform size and then mixed with grout. Small particles and free liquids would be immobilized with this process and any pyrophoric or corrosive characteristics of the TRU waste would be eliminated. Shred and grout treatment may also reduce the gas generation potential of TRU waste forms that already meet WAC. The gas generation potential in this case refers to the production of methane and other gases by rusting metals and decomposing materials.

An optimum shred and grout process for TRU waste treatment has not yet been selected by DOE. Site-specific NEPA review would be prepared by the Department if this type of treatment were selected for use at the treatment sites. The process selected may be modeled after commercially available technology.

Shredding TRU waste would be accomplished through a mechanical device that cuts, tears, or breaks the TRU waste into small uniform pieces. Most commercially available shredders feed the material between counter-rotating drums with intermeshing knives or teeth. For example, RFETS purchased a shredder that is designed to reduce graphite molds, HEPA filters, and process filters to pieces no larger than 2.5 x 5 x 5 centimeters (1 x 2 x 2 inches). The WIPP *Engineered Alternatives Cost/Benefit Study Final Report* (DOE 1995b) describes a shredding process that would result in pieces with a maximum dimension of 10 centimeters (4 inches).

Both organic and inorganic solid TRU waste would be suitable for treatment by shred and grout. Shredding generally reduces the TRU waste volume by allowing more efficient packing of smaller pieces; however, adding grout tends to increase the overall volume by about 20 percent.

Portland cement, sand, and fresh water are typically used to make grout. An alternate formulation has a cement base, salt for aggregate rather than sand, and simulated WIPP brine in place of fresh water. Additives would be used to control the long-term behavior of the grout. In addition, the formulation and application of the grout could be optimized for various TRU waste streams. For example, one process would combine the TRU waste and the grout before placing the mix in

drums; another would add TRU waste and grout in alternating layers and then vibrate the drums; a third process would add grout to drums filled with TRU waste and then vibrate the drums.

TRU waste treatment facilities would check waste drums for radioactive contamination, decontaminate as necessary, then weigh, label, and temporarily seal the drums. After letting the grout mixture cure for several days, waste drums would undergo an inspection, and permanent lids would be installed. Finally, waste drums would undergo inspection to certify that they meet planning-basis WAC.

Much of the shred and grout treatment would be conducted using remote handling techniques, even for CH-TRU waste, because of the potential for airborne contaminant release during the shredding process. Facilities and processes would be designed to protect workers, the public, and the environment from exposure to radioactive and hazardous materials.

2.2.3 Thermal Treatment

Thermal treatment of TRU mixed waste would be designed to meet the LDRs as well as similar requirements of the TSCA. Such treatment would destroy or immobilize the hazardous substances that RCRA and TSCA regulate. (Although thermal treatment to meet RCRA LDRs would otherwise be necessary for about 60 percent of the TRU waste that DOE owns or is responsible for, the recent amendments to the LWA in Public Law 104-201 exempts WIPP disposal from such RCRA requirements.) DOE is currently pursuing plans to use a thermal treatment process at Idaho National Engineering and Environmental Laboratory to treat both TRU mixed waste and TRU waste commingled with PCBs. Existing or future NEPA documentation has or would be prepared by the Department for these treatment facilities.

Thermal treatment involves exposing TRU waste to temperatures in excess of 3,000 degrees Celsius (°C) (5,400 degrees Fahrenheit [°F]). Nearly all TRU mixed waste streams in the DOE complex could be treated thermally, including solid combustibles and heterogeneous debris. The high temperatures would destroy organic materials and convert inorganic components to either a glassy slag, a metal phase, or a consolidated waste form. These phases could be separated out and offer the potential for recycling. Such high temperature treatment processes might also include a secondary, fuel-fired combustion chamber for treating off-gases to ensure a high efficiency in destroying all organic materials, regardless of the initial properties of the TRU waste.

Most of the alpha-emitting radionuclides and heavy metals would be bound as oxides in the slag, which would be expected to pass the EPA toxicity characteristics leach procedure. Thermal treatment may offer improved waste isolation because radionuclides and heavy metals in the slag would be less soluble in the brine and, in the event of human intrusion by drilling, less waste would be drawn to the surface in the drilling muds. The gas generation potential of thermally treated waste would also be less than that of untreated TRU waste.

The thermal process would produce aqueous liquids that would need to be neutralized and wet solids, debris, and residues that would need to be disposed of as low-level waste (DOE 1997). DOE would consider the impacts of these waste streams in future NEPA studies when selecting a specific thermal treatment process (i.e., vitrification, plasma hearth, etc.) and a specific site for a treatment facility.

Potential thermal treatment processes are discussed in a 1995 DOE publication entitled *Alternatives to Incineration Technical Area Status Report* (DOE 1995a). Summaries of three of these processes follow:

Plasma Torch and Electric Arc Technologies

Both the plasma torch and electric arc technologies involve a high-voltage discharge in a gas to form a plasma. They differ in that the plasma torch process involves plasma discharge in a flowing gas that stabilizes the arc and provides the thermal source. In contrast, the electric arc process involves plasma discharge in a nonflowing gas medium that provides the primary energy for heating and melting the TRU waste. The two plasma technologies can accept a variety of TRU wastes and TRU waste matrices. Depending on the system design, TRU waste liquids, soils and sludges, and even entire containers may be melted to form a molten slag.

A reducing environment is typically used to thermally treat volatile organic constituents. Process byproducts are synthetic off-gases and organics, which are combusted in an afterburner. Because very small gas volumes are used in these systems, only small volumes of off-gas are produced. Molten solid material can be continuously removed by overflow or poured by batch to form a leach-resistant, vitrified (glassy) TRU waste form.

Vitrification

Vitrification is the process of converting materials into a glass or glass-like substance. Temperatures used in this process are typically between 1,000°C to 1,600°C (1,800°F to 2,900°F). Thermal vitrification processes destroy organic constituents by pyrolysis or combustion. These processes also immobilize inorganics by incorporating them in the glass product. Various types of electric melters could be used to vitrify TRU waste, including vertical and horizontal joule, induction, microwave, and plasma and electric arc melters.

In the joule, induction, and microwave melters, molten glass is heated internally to form a pool of molten glass in a refractory lined or “cold wall” steel vessel. In many of these melters, a cold cap, or crust, is formed on the top of the melt from the feed as it is introduced to the top of the melter. This cap would act as the interface between incoming TRU waste and the molten glass. The bottom of the cap forms an interface where the feed material melts as it enters the glass matrix. The cold cap also serves to filter particulates and to condense and retain volatilized radionuclides and heavy metals for possible reincorporation into the melt. Water and organics volatilize from the cap and enter the plenum, a pressurized enclosure where the organics may be oxidized or reformed with the steam. Organic destruction may also occur through pyrolysis in the melt or in a secondary combustion chamber.

Molten Salt

The molten salt oxidation process consists of a bath of molten salts maintained at 700°C to 950°C (1,300°F to 1,700°F) to oxidize organic components of TRU mixed waste and to retain radionuclides, metals, and acid gases in a salt residue. During operation, a mixture of liquid or solid particulate TRU waste and air is injected into the bottom of the melt which is contained in a ceramic-lined vessel. The high temperature and intimate contact with the molten salt causes the rapid reaction of the organic material with the oxygen in the air to produce conventional combustion products.

The final products of this process would be a glass or ceramic slag, a metal ingot (depending on the original TRU waste form), and treated off-gas. This treatment process would reduce the original TRU waste volume by about 35 percent or less. The glass or ceramic slag product would contain all or most of the TRU waste. The metal ingot product could be sufficiently free of radionuclides that it would be suitable for disposal as low-level waste or recycled material. In either case, the slag and potentially the metal ingot would be characterized for certification to meet the planning-basis WAC. Most materials recovered from the off-gases would be cycled to ensure their incorporation into the slag. The treated off-gas would meet facility-specific release limits, as dictated by facility permits.

2.3 STAKEHOLDER OUTREACH AND INVOLVEMENT ACTIVITIES

DOE conducted several activities prior to the SEIS-II public scoping period to inform the public of the Department's intent to prepare SEIS-II. Letters were sent to SEIS-II stakeholders, including private citizens, elected officials, tribal leaders, and public affairs officers, announcing the Department's plan to prepare SEIS-II. A Fact Sheet and the DOE Carlsbad Area Office Monthly Stakeholder Calendar for August 1995 were also distributed to stakeholders to notify the public of the upcoming SEIS-II scoping activities. In addition, an informal telephone survey was conducted to gather stakeholder suggestions about the structure of the SEIS-II scoping meetings.

SEIS-II public scoping activities included the following:

- A Notice of Intent (NOI) published in the Federal Register on August 23, 1995 (60 FR 43779), and a notice reopening the comment period published in the Federal Register on October 13, 1995

- A public comment period from August 23, 1995, to October 16, 1995

- Public scoping meetings held in Carlsbad, New Mexico, on September 7, 1995; Albuquerque, New Mexico, on September 12, 1995; Santa Fe, New Mexico, on September 14, 1995; Denver, Colorado, on September 19, 1995; Boise, Idaho, on September 20, 1995; and a second meeting in Denver, Colorado, on October 11, 1995

The NOI listed the times and locations of the public scoping meetings and the length of the public scoping period.

The Department issued the Implementation Plan for SEIS-II in May 1996. The Implementation Plan provides background information on WIPP, describes the Department's purpose and need for the WIPP project, and describes the SEIS-II work plan. It also describes the scoping process, major issues identified during the scoping process, and contains a brief discussion of how major scoping issues will be addressed in SEIS-II. Copies of the Implementation Plan were distributed to state, tribal and local governments, U.S. Congressional delegates from states with an interest in the WIPP project, all parties who provided scoping comments, and other interested parties.

Fact Sheets were prepared by the Department to provide stakeholders with additional information on topics related to SEIS-II. Two Fact Sheets, one on prescoping activities and the other on postscoping activities, have been distributed to parties on the SEIS-II mailing list. Fact Sheets were also distributed at the public scoping meetings. These sheets provided information on the NEPA process, the WIPP project, the DOE reading rooms, the role of public participation in the

decision process, and other topics relevant to SEIS-II. The Department also will distribute Fact Sheets upon completion of the Final SEIS-II and publication of the ROD to all parties on the SEIS-II mailing list.

DOE published the Draft SEIS-II Notice of Availability (NOA) in the FR on November 29, 1996 (61 FR 60690). The NOA provided information on how the public could obtain copies and provide comments on the Draft SEIS-II, and the locations, dates, and times of the Draft SEIS-II hearings.

More than 900 copies of the Draft SEIS-II and 1,200 copies of the Draft SEIS-II Summary were distributed to federal, state, local, Tribal officials, and the general public. Three fact sheets were distributed along with the Draft SEIS-II and the Summary: an overview of how the public could provide comments on the Draft SEIS-II and the public hearing schedule; a list of the SEIS-II reading rooms (which has been reprinted as Table 2-4); and a list of the alternatives analyzed in the Draft SEIS-II.

DOE had initially established a 60-day public comment period that included the public hearing process. In response to public requests for more time to study the Draft SEIS-II, DOE subsequently extended the public comment period to 90 days (62 FR 4989). The public was also provided the opportunity to comment at a series of public hearings held in the following locations: Albuquerque, New Mexico on January 6 and 7, 1997; Santa Fe, New Mexico on January 8, 9, 10, 1997; Carlsbad, New Mexico and Denver, Colorado on January 13, 1997; Richland, Washington and Boise, Idaho on January 15, 1997; Oak Ridge, Tennessee on January 21, 1997; and North Augusta, South Carolina on January 23, 1997.

More than 700 individuals attended the hearings and more than 300 individuals provided oral testimony. The SEIS-II public hearings were scheduled after the holiday season to afford more people the opportunity to attend them. In addition, DOE staff attended meetings in New Mexico, Oregon, and Idaho to give presentations on SEIS-II. Recognizing that not every individual, organization, or agency could or would attend a public hearing, DOE invited comments on the Draft SEIS-II by mail, facsimile, and the Internet and received more than 150 letters.

Table 2-4
List of WIPP Reading Rooms

NAME	ADDRESS
U.S. Department of Energy Headquarters [a] Public Reading Room	Room 1E-190/Forrestal Building Freedom of Information Reading Room 1000 Independence Ave. S.W. Washington, DC 20585
Defense Nuclear Facilities Safety Board [a]	625 Indiana Ave. N.W., Suite 700 Washington, DC 20004
Scientific and Technical Information Center U.S. Department of Energy Reading Room [a]	P.O. Box 62 Oak Ridge, TN 37831
Thomas Branigan Memorial Library	200 East Picacho Las Cruces, NM 88001
New Mexico State Library [a]	325 Don Gaspar Santa Fe, NM 87503
Pannell Library New Mexico Junior College	5317 Lovington Highway Hobbs, NM 88240
Carlsbad Public Library [a] Public Document Room	101 South Halagueno Carlsbad, NM 88220
Zimmerman Library University of New Mexico [a] Government Publications	Roma Ave. and Yale Blvd. Albuquerque, NM 87131-1466
Martin Speare Memorial Library	New Mexico Institute of Mining and Technology Leroy and Bullock Campus Station Socorro, NM 87801
U.S. Department of Energy FOIA Public Reading Room	Technical-Vocational Institute Montoya Campus Library 4700 Morris NE Albuquerque, NM 87111
Raton Public Library	244 Cook Ave. Raton, NM 87740
New Mexico State University Library	P.O. Box 30001 Las Cruces, NM 88003
U.S. Department of Energy Public Reading Room [a]	1776 Science Center Dr. Idaho Falls, ID 83702
INEEL Boise Office	816 West Bannock Suite 306 Boise, ID 83702
Shoshone-Bannock Library HRDC Building	Bannock and Pima Fort Hall, ID 83203
University of Idaho Library University of Idaho	Rayburn St. Moscow, ID 83202
Moscow Environmental Restoration Information Office	530 South Ashbury Suite 2 Moscow, ID 83842
Pocatello Public Library	113 South Garfield Pocatello, ID 83201
Idaho State University Library	741 South 7th Ave., Box 8089 Pocatello, ID 83209
Twin Falls Public Library	434 2nd St. East Twin Falls, ID 83301
Standley Lake Library	8485 Kipling St. Arvada, CO 80005
Superfund Records Center U.S. Environmental Protection Agency	999 18th St. 5th Floor Denver, CO 80202
U.S. Department of Energy Public Reading Room Rocky Flats Operations [a]	Front Range Community College Library 3645 West 112th Ave. Level B, Center of the Building Westminster, CO 80030
Citizens Advisory Board	9035 N. Wadsworth Pkwy Suite 2250 Westminster, CO 80021

[a] Reference documents are available at these locations

Table 2-4
List of WIPP Reading Rooms — Continued

NAME	ADDRESS
U.S. Department of Energy Public Reading Room Richland Operations Office	Washington State University Tri-Cities 100 Sprout Rd. Room 130 West Richland, WA 99352
U.S. Department of Energy Public Reading Room	9800 South Cass Ave. Building 201 Argonne, IL 60439
U.S. Department of Energy Public Reading Room Nevada Operations Office	2621 Losee Rd. North Las Vegas, NV 89030-4129
U.S. Department of Energy Public Reading Room Oakland Operations Office	1301 Clay St. Room 700 N Oakland, CA 94612
U.S. Department of Energy Public Reading Room	Miamisburg Senior Adult Center 305 Central Ave. Miamisburg, OH 45342
Texas State Library Information Services Division	1201 Brazos St. Austin, TX 78701
Wyoming State Library Government Documents	Supreme Court Building 2301 Capitol Ave. Cheyenne, WY 82002
Idaho National Engineering and Environmental Laboratory Pocatello Office	1651 AT Ricken Dr. Pocatello, ID 83201
Idaho National Engineering and Environmental Laboratory Twin Falls Office	233 2nd St. North Suite B Twin Falls, ID 83301
Information Center Colorado Department of Public Health and Environment	4300 Cherry Creek Dr. South Building A Denver, CO 80222-1530
U.S. Department of Energy Public Reading Room	55 Jefferson Cir. Oak Ridge, TN 37830
Community Reading Room	Los Alamos National Laboratory P.O. Box 1663, MS A-117 Los Alamos, NM 87545
Mobile Public Library Federal Document Collection	701 Government St. Mobile, AL 36602-1499
Arkansas State Library Federal Document Collection	One Capitol Mall Little Rock, AR 72201
Flagstaff City-Coconino County Public Library	300 West Aspen Flagstaff, AZ 86001
Atlanta-Fulton Public Library Federal Document Collection	One Margaret Mitchell Square, N.W. Atlanta, GA 30303-1089
Indiana State Library Federal Document Collection	140 North Senate Ave. Indianapolis, IN 46204-2296
Kansas State Library Federal Document Collection	State Capitol Building Topeka, KS 66612
Mississippi State Law Library Federal Document Collection	450 High St. Jackson, MS 39215-1040
Missouri State Library Federal Document Collection	600 West Main Jefferson City, MO 65102
Oregon State Library Federal Document Collection	State Library Building 250 Winter Street, N.E. Salem, OR 97310-0640
The Navajo Nation U.S. Environmental Protection Agency	c/o Levon Benally, Jr. P.O. Box 339 Window Rock, AZ 86515
State Library Louisiana	760 North Third St. Baton Rouge, LA 70802
The Oklahoma Department of Libraries	200 N.E. 18th St. Oklahoma City, OK 73105

[a] Reference documents are available at these locations

2.4 REFERENCES CITED IN CHAPTER 2

DOE (U.S. Department of Energy), 1980, *Final Environmental Impact Statement for the Waste Isolation Pilot Plant*, DOE/EIS-0026, October, Washington, D.C.

DOE (U.S. Department of Energy), 1990, *Final Supplement Environmental Impact Statement for the Waste Isolation Pilot Plant*, DOE/EIS-0026-FS, January, Washington, D.C.

DOE (U.S. Department of Energy), 1994, *TRUPACT-II Content Codes (TRUCON)*, DOE/WIPP 89-004, Revision 8, WIPP Project Office, Carlsbad, New Mexico.

DOE (U.S. Department of Energy), 1995a, *Alternatives to Incineration Technical Area Status Report*, DOE/MWIP-26, April, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1995b, *Engineered Alternatives Cost/Benefit Study Final Report*, WIPP/WID 95-2135, September, Carlsbad, New Mexico.

DOE (U.S. Department of Energy), 1995c, *Radioactive Waste Processing and Volume Reduction Technology Study*, DOE/CAO-95-3102, October, Carlsbad, New Mexico.

DOE (U.S. Department of Energy), 1995d, *Transuranic Waste Baseline Inventory Report*, DOE/CAO-95-1121, Revision 2, December, Carlsbad, New Mexico.

DOE (U.S. Department of Energy), 1995e, *Transuranic Waste Characterization Quality Assurance Program Plan*, DOE/CAO-94-1010, Carlsbad, New Mexico.

DOE (U.S. Department of Energy), 1996a, *Comment Responses and Revisions to the Resource Conservation and Recovery Act Part B Permit Application*, DOE/WIPP 91-005, Revision 5.2, January, Carlsbad, New Mexico.

DOE (U.S. Department of Energy), 1996b, *Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, DOE/WIPP-069, Revision 5, April, Carlsbad, New Mexico.

DOE (U.S. Department of Energy), 1996c, *Final No-Migration Variance Petition*, DOE/CAO-96-2160, June, Carlsbad, New Mexico.

DOE (U.S. Department of Energy), 1996d, *Transuranic Waste Baseline Inventory Report*, DOE/CAO-95-1121, Revision 3, June, Carlsbad, New Mexico.

DOE (U.S. Department of Energy), 1996e, *Title 40 CFR 191 Combliance Certification Application for the Waste Isolation Pilot Plant*, DOE/CAO-2184, October, Carlsbad, New Mexico.

DOE (U.S. Department of Energy), 1997, *Final Waste Management Programmatic Environmental Impact Statement*, DOE/EIS-0200-F, May, Washington, D.C.

CHAPTER 3
DESCRIPTION OF THE PROPOSED ACTION AND ALTERNATIVES

The following sections provide descriptions of the Proposed Action, three action alternatives, and two no action alternatives. Section 3.4 presents a summary table of the Proposed Action and alternatives. The chapter closes with a discussion of the alternatives that are not analyzed in detail in this second supplemental environmental impact statement (SEIS-II), a summary of impacts, and a detailed discussion of the preferred alternative.

In the Notice of Intent that initiated the public scoping process for SEIS-II, the Department of Energy (DOE or the Department) preliminarily identified a Proposed Action, two action alternatives, and a no action alternative. Comments received during the scoping process identified the need for an additional action alternative and another no action alternative.

The Proposed Action, three action alternatives, and two no action alternatives presented in this chapter, therefore, comprise a wide range of options from which the Department can make decisions. Among the decisions that can be supported by these options are the following:

- Whether to open the Waste Isolation Pilot Plant (WIPP) for disposal of transuranic (TRU) waste or continue to maintain the waste in storage. The two no action alternatives examine the impacts of not opening WIPP.

- Which portions of contact-handled (CH) TRU and remote-handled (RH) TRU waste inventory (identified in Chapter 2 as the Total Inventory consisting of the Basic Inventory and Additional Inventory) should be disposed of at WIPP or continued in storage. Analyses of the alternatives include the impacts of both inventories.

- Which minimal level of waste treatment should be required in the Waste Acceptance Criteria (WAC) to meet disposal performance standards or storage requirements prior to the disposal of or storage of waste.[1] The three action alternatives differ in the treatment proposed, as do the two no action alternatives.

FURTHER NEPA ANALYSIS

The Department would conduct site-specific National Environmental Policy Act (NEPA) analyses to assess the impacts of siting and operating individual waste treatment facilities before making final decisions concerning whether to construct and operate those facilities.

- Whether to transport TRU waste primarily by truck or by rail. Three transportation options (truck, commercial rail, and dedicated rail) are assessed for all alternatives except the Proposed Action, where transportation by truck is the only option considered, and No Action Alternative 2, where there is no transportation.

[1] DOE may decide, for site-specific reasons, to treat TRU waste to levels beyond the minimal level ultimately required in the WAC. Such a decision would be based on further site-specific NEPA review.

Decisions based on SEIS-II may be a combination of the options presented within the alternatives analyzed. This means that portions of two or more of the alternatives analyzed in SEIS-II may be combined and used by the Department for the management or disposal of TRU waste.

The Preferred Alternative is the Proposed Action, reserving the possibility of using rail transportation in the future following appropriate NEPA review. Additional detail on the Preferred Alternative is presented at the end of this chapter.

The following sections describe the Proposed Action; Action Alternatives 1, 2, and 3; and No Action Alternatives 1 and 2.

3.1 PROPOSED ACTION: BASIC INVENTORY, TREAT TO WAC, DISPOSE OF AT WIPP (PREFERRED ALTERNATIVE RESERVING RAIL TRANSPORTATION FOR FUTURE CONSIDERATION)

The Department's Proposed Action is to continue with the phased development of WIPP by disposing of TRU waste at the facility, as authorized by Public Laws 96-164, 102-579, and 104-201. For the purposes of analyses in this document, WIPP disposal is assumed to begin in 1998. Under the Proposed Action, DOE would dispose of defense TRU waste that has been placed in retrievable storage and that would continue to be generated from plutonium stabilization and management, environmental restoration, decommissioning activities, waste management programs, and testing and research during the 35-year period from 1998 to 2033 (i.e, waste included in the Basic Inventory). Table 3-1 presents the volume of TRU waste included in this Basic Inventory.

However, SEIS-II analyses assumed disposal of 7,080 cubic meters (250,000 cubic feet) of RH-TRU waste, much less than the RH-TRU waste Basic Inventory. This volume was analyzed because it is the volume allowed by the Consultation and Cooperation (C&C) Agreement with the State of New Mexico. For CH-TRU waste, SEIS-II analyses were performed using a disposal volume of 168,500 cubic meters (5,950,000 cubic feet), which is greater than the CH-TRU waste Basic Inventory. This volume was analyzed because when added to the RH-TRU waste volume above, the total disposal volume was that allowable under the Land Withdrawal Act (LWA).

(More recent waste volume estimates presented in Appendix J show a decrease in the volume of RH-TRU waste, to a volume that could be completely disposed of at WIPP. As explained in Chapter 2, the SEIS-II analyses are based on a more conservative inventory.)

Management at WIPP of the Additional Inventory described in Chapter 2 is not analyzed as part of the Proposed Action. Alternatives for management of the Additional Inventory are presented in Action Alternatives 1, 2, 3, and No Action Alternative 1, discussed later in this chapter. Existing RH-TRU waste in the Basic Inventory that exceeds the amount allowable by current laws and agreements is identified as "excess waste." It was assumed, for the purposes of analyses, that the excess RH-TRU waste, which amounts to approximately 43,000 cubic meters (1,500,000 cubic feet), would be located at the Hanford Site (Hanford) and Oak Ridge National Laboratory (ORNL) and would remain in storage at these sites for an indefinite number of years following treatment.[1]

[1] For the purposes of analyses in SEIS-II, it was assumed that waste would be shipped from all four RH-TRU waste consolidation sites at similar rates so that the entire projected INEEL and LANL RH-TRU waste volumes would be accepted, and the remaining capacity for RH-TRU waste disposal would be filled proportionally with waste from ORNL and Hanford. New waste estimates presented in Appendix J indicate that all waste may be disposed of.

Table 3-1
TRU Waste Volumes (Basic Inventory) for the Proposed Action [a]

Site [c]	Site Volume Through 2033 (cubic meters)		Pretreatment Consolidated Volume [b] (cubic meters)		Post-Treatment Disposal Volume (cubic meters)	
	CH-TRU	RH-TRU	CH-TRU	RH-TRU	CH-TRU [d]	RH-TRU [e]
Hanford Site (Hanford)	57,000	29,000	57,000	29,000	57,000	42,000
Los Alamos National Laboratory (LANL)	21,000	230	21,000	230	21,000	330
Idaho National Engineering and Environmental Laboratory (INEEL) [f]	28,000	220	29,000	2,000	30,000	2,800
Argonne National Laboratory - West (ANL-W)	1,000	1,700	--- [g]	---	---	---
Argonne National Laboratory - East (ANL-E)	200	---	200	---	200	---
Savannah River Site (SRS)	12,000	---	12,000	---	12,000	---
Rocky Flats Environmental Technology Site (RFETS)	11,000	---	11,000	---	17,000	---
Oak Ridge National Laboratory (ORNL)	1,700	3,100	1,800	3,700	1,900	5,300
Lawrence Livermore National Laboratory (LLNL)	1,200	---	1,200	---	1,200	---
Nevada Test Site (NTS)	630	---	630	---	630	---
Mound Plant (Mound)	300	---	300	---	340	---
Bettis Atomic Power Laboratory (Bettis)	170	9	---	---	---	---
Sandia National Laboratories - Albuquerque (SNL)	17	---	---	---	---	---
Paducah Gaseous Diffusion Plant (PGDP)	8	---	---	---	---	---
U.S. Army Materiel Command (USAMC)	3	---	---	---	---	---
Energy Technology Engineering Center (ETEC)	2	7	---	---	---	---
University of Missouri Research Reactor (U of Mo)	1	---	---	---	---	---
Ames Laboratory – Iowa State University (Ames)	1	---	---	---	---	---
Battelle Columbus Laboratories (BCL)	---	580	---	---	---	---
Total	**135,000**	**35,000**	**135,000**	**35,000**	**143,000** [h]	**50,000** [i]
Disposal Volume Allowed by LWA and the C&C Agreement	**---**	**---**	**---**	**---**	**168,500** [h]	**7,080** [i, j]

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 parts per million (ppm) of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Volumes have been rounded. Actual totals may differ due to rounding. The site volumes through 2033 match the final columns on Table 2-2.

[b] Volumes include consolidation of waste as indicated on Figure 3-1.

[c] Sites in boldface were included in SEIS-I.

[d] Post-treatment volumes have been adjusted to meet packaging and transportation requirements to meet planning-basis WAC.

[e] Values represent WIPP emplacement volumes, except for Hanford and ORNL which may not be able to emplace all of their RH-TRU waste at WIPP. (New volume estimates, as presented in Appendix J, indicate all waste could be emplaced.)

[f] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, are counted as one site in SEIS-II.

[g] Dashes indicate no waste.

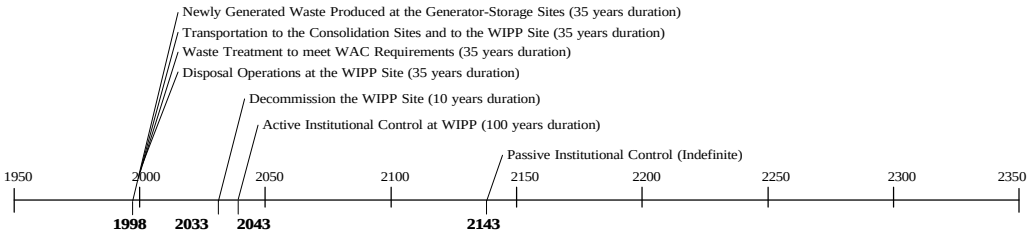
[h] Though 143,000 cubic meters of CH-TRU waste are part of the Basic Inventory, additional CH-TRU waste may become a part of that inventory should RCRA or CERCLA action lead to retrieval of previously disposed of waste. Therefore, SEIS-II assesses the impact of the entire disposal volume allowed, 168,500 cubic meters.

[i] All LANL and INEEL RH-TRU waste is assumed to be disposed of; RH-TRU waste disposed of for Hanford would be approximately 2,800 cubic meters; that for ORNL would be 1,100 cubic meters (after consolidation).

[j] The LWA limits the total RH-TRU waste curie content of WIPP to 5.1 million. Under the Proposed Action, the total curie content associated with the 7,080 cubic meters would be less than 1 million curies.

Current data and projections indicate that 18 sites would generate Basic Inventory waste or currently have it in storage. TRU waste would first be treated at the 18 sites as necessary to meet planning-basis WAC. Consolidation under the Proposed Action would occur in the manner described in the ROD to be issued for the *Final Waste Management Programmatic Environmental Impact Statement* (WM PEIS) (DOE 1997). Such consolidation could be at the 10 largest generator-storage sites (see Figure 3-1) as in the WM PEIS Decentralized Alternative or at fewer sites as in the WM PEIS (DOE 1997) preferred alternative. For purposes of analysis, SEIS-II assumed consolidation at the 10 largest generator-storage sites; not consolidating the waste and consolidating it in a manner similar to the WM PEIS preferred alternative are also discussed in the text.[1]

The timeline below presents the approximate schedule for waste disposal activities under the Proposed Action. The disposal of TRU waste at WIPP would begin in 1998 and continue for 35 years, through the year 2033, at which time the facility would be closed. Decommissioning activities of WIPP would take up to 10 years (2043) and would be followed by an active institutional control period assumed for analyses to last 100 years, ending in 2143.



Timeline for the Implementation of the Proposed Action

3.1.1 Activities at the Generator-Storage Sites

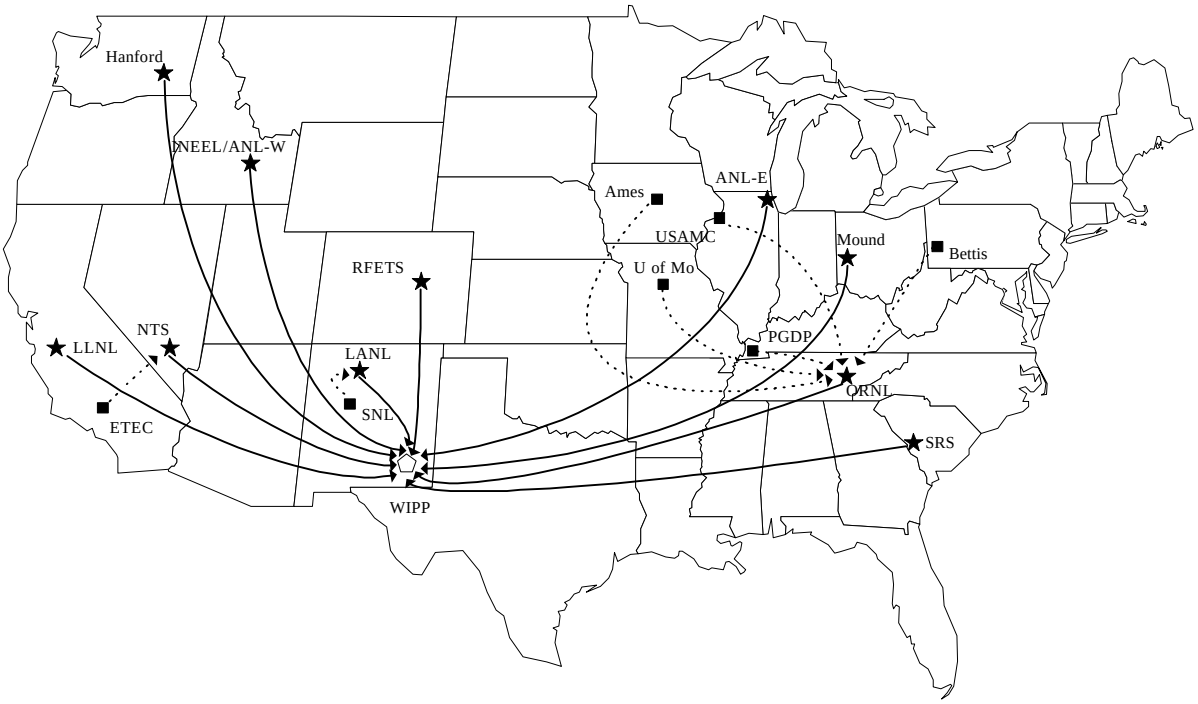
This section describes WIPP-related activities that would occur under the Proposed Action at various generator-storage sites throughout the DOE complex. The WM PEIS and Chapter 4 of SEIS-II contain information on the sites themselves.

The 18 generator-storage sites would consolidate CH-TRU waste at 10 consolidation sites for subsequent shipment to WIPP. Of the seven RH-TRU waste sites, three sites would ship their RH-TRU waste for consolidation prior to shipment to WIPP. The flow of waste described here is assumed for analysis of potential environmental impacts, but the Department may adjust the configuration later in the WM PEIS Record of Decision.

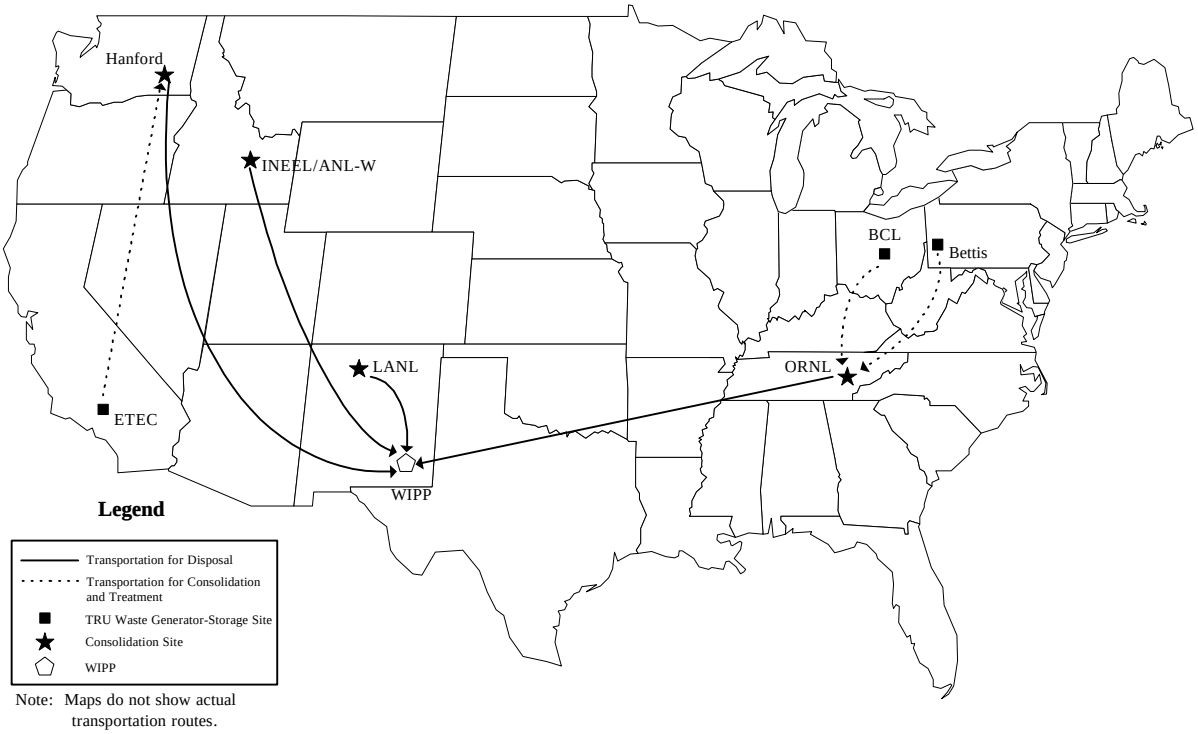
The type of treatment performed would depend on whether the waste is already certified as meeting WAC. Some waste may require treatment and packaging to meet WAC. For purposes of analysis, all waste has been assumed to be treated and packaged to

[1] The consolidation scheme presented in SEIS-II is intended for the purpose of analyzing the impacts and may not reflect the actual movement of waste that will occur.

CH-TRU Waste



RH-TRU Waste



Note: Maps do not show actual transportation routes.

Figure 3-1
Movement of Waste for the Proposed Action [a]
(For complete names of facilities and waste volumes, see Table 3-1)

[a] Although Pantex currently has no TRU waste, future decisions by the Department may result in TRU waste generation at Pantex.

planning-basis WAC (using mobile treatment units where appropriate).[1] This could include, for example, reducing size and packaging, adding absorbents to eliminate free liquids, packaging, and assaying and sampling to ensure that packaging and transportation certification criteria have been met.

One aspect of the WAC addresses the generation of hydrogen gas in the TRUPACT-II during shipment. The assumption has been made that all CH-TRU waste will be packaged using bagless posting (i.e., no plastic bag liners will be used in waste containers). Bagless posting offers a lower gas generation rate than using one or more layers of plastic bagging materials and therefore results in fewer shipments (see Appendix A).

Each site preparing to ship TRU waste to WIPP would coordinate with WIPP personnel for scheduling purposes. Together, site and WIPP personnel would arrange for shipment from the site to WIPP using either the TRUPACT-II or the RH-72B cask.

3.1.2 Transportation Activities

Under the Proposed Action, trucks transporting TRU waste in U.S. Nuclear Regulatory Commission (NRC)-certified transportation containers (certified under 10 CFR Part 71) and traveling over U.S. Department of Transportation (DOT) and state-designated routes would transport the TRU waste between the generator-storage sites and from the consolidation sites to WIPP. Trucks would transport CH-TRU waste in TRUPACT-IIs and RH-TRU waste in RH-72B casks. The rate at which both CH-TRU waste and RH-TRU waste would arrive at WIPP for disposal would be based on the WIPP waste handling throughput rate and the storage area. On average, WIPP facilities would handle about 50 TRUPACT-IIs of CH-TRU waste and about eight RH-72B casks of RH-TRU waste per week. WIPP currently has no permits to store backlogged shipments, although it may obtain a permit to store small amounts of waste in its Waste Handling Building. DOE proposes to obtain the Resource Conservation and Recovery Act (RCRA) permits for limited nonroutine storage capacity in the Waste Handling Building (see Figure 2-3), but the time that incoming waste can spend in the staging area is limited. The Safety Analysis Report for Packaging attached to Certificate of Compliance No. 9218 (NRC 1997) limits the time a TRUPACT-II can remain sealed (with waste inside) to a maximum of 60 days, due to the potential for hydrogen gas accumulation within the TRUPACT-II. WIPP operations managers would meet these requirements through continuous coordination with the treatment sites to control the time and rate at which CH-TRU and RH-TRU waste arrives at WIPP for disposal.

Currently, the Department is proposing the use of trucks to transport waste. The Department has investigated and continues to investigate the possibility of using rail transportation but considers it less reasonable at this time. The primary factors that make rail carriage less reasonable are the following: (1) limited interest of the rail carriers in handling the shipments, (2) higher cost of dedicated rail transportation as compared to truck transportation, (3) the initial cost of acquiring additional TRUPACT-IIs needed for rail transportation (because three times as many TRUPACT-IIs would be needed for each shipment) and of acquiring or modifying rail cars for transport, and (4) DOE's inability to obtain rail carrier assurance that TRUPACT-II transit will

[1] At the smaller sites, use of mobile characterization and/or treatment units was assumed. Any emissions from these mobile units would be HEPA (High Efficiency Particulate Air) filtered. The characterization, packaging, and treatment performed by the mobile units would be on such a small volume of waste that there would be virtually no additional waste, and virtually no radiological or hazardous chemical impacts to workers or the public would be expected.

TRANSCOM SYSTEM

DOE has developed a transportation tracking and communications system that is used to track truck and rail shipments. This satellite-based system, the Transportation Tracking and Communications (TRANSCOM) system, has been in operation since 1989. Since its inception, the TRANSCOM System has tracked over 500 shipments for DOE. The use of TRANSCOM is mandated by DOE Order 460.2, *Departmental Materials Transportation and Packaging Management*.

The mission of the TRANSCOM system is to provide tracking and communications for shipments of radioactive materials, hazardous materials, and other high-visibility shipping campaigns, as specified by DOE. The TRANSCOM system is managed and operated at the TRANSCOM Control Center (TCC) in Oak Ridge, Tennessee, for DOE.

The TRANSCOM system provides the TCC staff, shippers, carriers, receivers, and state, Tribal, and federal users with the ability to view information about shipments and communicate with each other during shipment tracking. Information about shipment contents, points of contact, routes, status, locations, and emergency response information is available to local emergency response teams and each user. The information is displayed in tabular and graphical form using a series of national, state, and county maps. The vehicle location can be determined to within a few meters, with position updates as frequently as every 60 seconds. Drivers are alerted to adverse weather or road conditions.

enable DOE to unseal the TRUPACT-II within 60 days, as required by NRC. Regular rail transportation, because of its lower cost and accident risk, is still considered a desirable option for some waste transportation in the future, provided the factors that make it currently less reasonable can be mitigated. Though rail transportation was not analyzed under the Proposed Action, use of rail transportation is reserved for future consideration under the Preferred Alternative; if rail transportation were used, impacts are expected to be lower than impacts from truck transportation.

3.1.2.1 Shipping Procedures

The DOE *Transuranic Materials Transportation Guide* (DOE 1996b) establishes the procedures to be followed for shipping TRU waste; essentially, these are the same procedures planned earlier and reported in the *Final Supplement Environmental Impact Statement for the Waste Isolation Pilot Plant* (SEIS-I) (DOE 1990). DOE personnel, the generator-storage sites, and the carriers would comply with all applicable rules, regulations, and orders pertaining to the packaging, marking, labeling, inspection, and transportation of TRU waste as issued by the DOT, DOE, the U.S. Environmental Protection Agency (EPA), and NRC.

Each generator-storage site would ensure that the TRU waste to be shipped meets WAC, that the waste is properly loaded into the TRUPACT-II or RH-72B cask, that all DOE procedures have been followed, that labels and placards are in compliance with DOT regulations, and that bills of lading are entered correctly into the TRANSCOM system. The generator-storage sites will follow the requirements for Type A packages described in Title 49, CFR Part 173. The Department would be prepared to provide emergency response support in the event of an accident.

A contract carrier would provide dedicated drivers and tractor-trailer trucks to transport TRU waste to WIPP. The trailers and packagings are owned by DOE. Specific responsibilities of the carrier would include providing drivers who are qualified according to DOT requirements (49 CFR Part 391) and ensuring that vehicles are operated in a safe manner. The carrier would ensure that both the tractor and the trailer are in operating condition prior to leaving the shipper's premises and

CONSERVATISM OF TRU WASTE VOLUME ESTIMATES

TRU waste inventory estimates, as used throughout SEIS-II, embody many conservative assumptions to ensure bounding analyses of maximum, reasonably foreseeable impacts. The following reflect some of the conservative assumptions.

- The BIR-3 estimates of TRU waste volumes include projections that may overestimate TRU waste volumes. For instance, in both the Basic Inventory and the Additional Inventory, volume estimates include projections of waste yet to be generated. Though the Department's TRU waste generation due to defense activities has decreased because of a change in the nation's nuclear weapons needs, the projections of future waste also include waste anticipated by activities such as decontamination and decommissioning. These activities, which would include cleaning and disassembling facilities, can generate a great deal of TRU waste, but whether that waste will actually be generated and whether it will be CH-TRU or RH-TRU waste is uncertain. For the purposes of analyses, SEIS-II has used the estimates included in BIR-3.

- The Additional Inventory includes estimates of TRU waste produced prior to 1970 and believed to have been disposed of in trenches at some of the sites. Since DOE's definition of TRU waste has changed and some of the buried waste would probably be classified as low-level waste under current definitions, the amount that is actually TRU waste is unknown. For the purposes of analyses, all of this waste, as estimated in BIR-3, is considered part of the Additional Inventory and the effects of its disposal at WIPP are assessed in the SEIS-II action alternatives. SEIS-II analyzes 141,000 cubic meters (5 million cubic feet) of TRU waste that has been previously disposed of. Currently, though, DOE estimates that only 80,000 cubic meters (2.8 million cubic feet) of this waste would be excavated.

- The C&C Agreement between the State of New Mexico and DOE limits the amount of RH-TRU waste allowable at WIPP to 7,080 cubic meters (250,000 cubic feet). The Department's Proposed Action proposes disposing of this amount of RH-TRU waste, although the actual amount may be as low as 4,300 cubic meters (150,000 cubic feet). The lower figure reflects the current plans for disposing of this waste in the walls of WIPP panel rooms before emplacement of CH-TRU waste in the rooms. At startup, delays in preparing the RH-TRU waste for shipment are anticipated, which would result in the emplacement of some CH-TRU waste before RH-TRU waste is ready for WIPP. To ensure that SEIS-II disposal analyses are conservative, the analyses for the Proposed Action were conducted as if the full 7,080 cubic meters of RH-TRU waste would be emplaced.

- Application of the LWA and the C&C Agreement would limit the amount of CH-TRU waste allowable under the Proposed Action to 168,500 cubic meters (5,950,000 cubic feet), but only 143,000 cubic meters (5,050,000 cubic feet) is estimated to be in the Basic Inventory. Still, because of the potential for excavation of previously disposed of waste (which would then be classified as newly generated) and the potential for treatment of alpha-emitting, low-level waste that could convert currently non-TRU waste forms into TRU waste by concentrating transuranic radionuclides (as discussed in the cumulative impacts analysis), and repackaging of RH-TRU waste to meet the criteria of CH-TRU waste, SEIS-II analyses consider the effects of filling WIPP to its allowable capacity.

- While the LWA and C&C Agreement include limits on the volume of TRU waste that can be emplaced, there is considerable uncertainty concerning how much of a container's volume is made up of TRU waste and how much is void space. Many of the containers would include a great deal of void space, particularly for RH-TRU waste; the actual volume of waste in a drum or cask, therefore, may be much less than the volume of the drum or cask. For the purposes of analyses in SEIS-II, the volume of the drum or cask is used, as if the drum or cask were full without void space.

While volume changes to the TRU waste inventory could reduce or increase the effects calculated in SEIS-II, the best estimates available have been used and conservative assumptions have been incorporated to ensure that the results would actually be less than those presented. A text box entitled "Factors to Consider in Combining Alternatives" (presented in Chapter 5) explains in more detail how the results would change as inventory volumes change.

during the trip. Drivers would be required to make routine visual safety inspections of the tractor, trailer, and containers either every 160 kilometers (100 miles) or every two hours, in addition to routine inspections required by DOE, DOT, and affected states. The carrier or any other person operating a motor vehicle that contains a Class 7 (radioactive) material for which placarding is required must comply with routing and training requirements in 49 CFR Part 397, Subpart D. Carriers would keep current copies of their maintenance certificates in their vehicles at all times.

In the event of an accident, the carrier driver would notify emergency first-responders via cellular phone and would notify the Central Monitoring Room (CMR) at WIPP via TRANSCOM. A senior DOE official or the DOE Carlsbad Area Office (CAO) Incident/Accident Team Leader would assist those in charge at the accident. DOE resources would be made available to local authorities, as appropriate, to support the mitigation of the accident, including, but not limited to, package recovery and site cleanup. In the event of an accident involving a fire, breach, release, or suspected radioactive contamination, the carrier would follow established procedures to obtain any needed federal, state, or local assistance or technical advice. Drivers would carry instructions for actions to be taken in the event of an accident and would be trained in package recovery procedures (see Appendix E). Any carrier accident, no matter how minor, would be reported to the CAO Transportation Manager, the WIPP Traffic Manager, the CMR operator, and DOE Headquarters Emergency Operations Center via the DOE Albuquerque Operations Office. If not already notified by the carrier, the shipper would be notified by the CMR operator.

Delays in scheduled arrival may occur from time to time due to weather conditions, maintenance checks, and other factors at the treatment sites. All schedule delays of two or more hours from the shipping, receiving, or transit time would be reported immediately to the CMR, which would notify the shipper or receiver, as appropriate. If a shipment were delayed, a new scheduled time of arrival would be arranged. There would be no “deadlines” for a shipment to be received at WIPP.

The carrier’s management plan provides guidance from the Western Governors Association and DOE on the selection of suitable safe parking areas. As instructed, carriers would use designated DOE or Department of Defense sites, or an area designated by the affected state as a safe parking area, in the event of a shipping layover. If no DOE, Department of Defense, or state-designated site were available, the driver would select a site based on criteria related to the nearby population size, proximity, and security and would notify the nearest state police district office.

3.1.2.2 Shipping Routes

Under the Proposed Action, transportation could include shipments between the generator-storage sites and from the 10 largest generator-storage sites to WIPP. The states through which the trucks would pass would designate shipment routes in consultation with DOE. Figures in Appendix E show the currently designated routes. These routes, as well as any chosen in the future, would comply with DOT requirements, use the Interstate Highway System or other state-designated roads, and use the shortest routes to access the interstate highways. The routes also would bypass urban areas if this could be done safely and efficiently. The requirements for state-routing designation are provided in 49 CFR Part 397, Subpart 103, and the procedures by which highway routing can be preempted are prescribed in 49 CFR Part 397, Subpart E.

3.1.3 Activities at WIPP

At the time of SEIS-I (DOE 1990), all surface facilities, shafts, and hoist facilities had been constructed. Underground, an initial waste disposal panel (Panel 1) had been excavated and was ready to accommodate the Test Phase activities (see Section 2.1.4). These physical facilities, which are described in SEIS-I, are essentially unchanged.

3.1.3.1 Excavation Operations

Under the Proposed Action, a total of ten panel-equivalents (in the panels and access tunnels) would be needed to dispose of the waste. DOE has excavated the first panel, which consists of seven disposal rooms and, from an engineering viewpoint, could receive waste now. The Department would excavate the additional disposal panels as needed. The Department estimates that it would require up to three years to excavate a panel.

The massive salt beds at a depth of 655 meters (2,150 feet) creep slowly in response to pressure from the overlying rock and would eventually cause the excavated openings within the salt beds to close. This is the reason why "just-in-time excavation" would be used. Just-in-time excavation is based on the concept that when additional room is needed for waste disposal, a new panel would be excavated and ready for use "just in time." This means that each panel would be excavated, filled, and closed in a time frame that would minimize the potential for hazardous conditions such as roof falls.

The Department would maintain each excavation (e.g., panel room) until it is filled. Personnel working underground would conduct a monitoring and excavation maintenance program in compliance with a long-term ground control plan (WID 1995). In addition to regular visual inspections, geotechnical instrumentation would provide continuous information about rock mass movement and deformation. Every underground worker would have the responsibility and authority to close a suspect area to entry until it has been inspected by excavation safety personnel. Unsafe or potentially unsafe areas would be remediated by bringing down loose rock or installing control measures such as wire mesh and roof bolts. The facilities would be inspected a minimum of four times a year by the Mine Safety and Health Administration, as required by Section 11 of the Land Withdrawal Act.

Salt that results from the excavation of the panels would be stored aboveground in the existing salt pile, which would be 12 hectares (30 acres) in size. Management of the salt pile may include selling or disposing of unneeded salt under the Materials Act of 1947. The salt pile would stabilize naturally, and a drainage pond would contain runoff. Salt would be retained at the site for potential use in permanent shaft seals and markers upon closure of WIPP.

3.1.3.2 TRU Waste Handling Operations at the Surface

CH-TRU waste would arrive at WIPP on tractor-trailer trucks, each of which can carry up to three TRUPACT-IIs. Thus, each truck shipment could deliver up to forty-two 55-gallon drums, six standard waste boxes of CH-TRU waste, or three Ten Drum Overpacks. RH-TRU waste would also arrive by truck. Each truck could carry one RH-72B cask. Each cask contains a canister holding up to three 55-gallon drums of RH-TRU waste or up to 0.89 cubic meters (31 cubic feet) if drums are not used inside the canister.

For CH-TRU waste, the Department has developed detailed procedures for unloading the trucks, opening the TRUPACT-IIs, inspecting the packages, preparing packages to be moved underground, and then moving them to the underground. Conceptually, the process is as follows: When a truck arrives at the Waste Handling Building, it would be inspected for load integrity and the presence of radioactive contamination. The truck would be unloaded, and the TRUPACT-IIs moved to a specially designed platform with equipment and testing facilities. Each time another barrier surface of the container assembly was uncovered, the waste packages would be checked for surface radiation levels and contamination. The packages then would be placed on pallets for transport to underground emplacement.

CH-TRU waste shipping packages or waste containers with surface contamination less than or equal to 20 disintegrations per minute alpha or 200 disintegration per minute beta/gamma would not need to be decontaminated prior to handling. If surface contamination on the exterior of the shipping package or waste container is detected in amounts less than 2,000 disintegrations per minute alpha or 20,000 disintegrations per minute beta/gamma over an area less than or equal to 0.56 square meters (6 square feet), the shipping package or waste container would be decontaminated prior to any further steps in the waste handling process (DOE 1996a). If surface contamination in excess of these levels was detected, the canister or drums would be put into an outer sleeve and a lid would be welded on using remote handling equipment. The shipping package or waste container would either be returned to the treatment site, shipped to a different DOE site if the original shipper does not have suitable facilities, or shipped to a non-DOE site for decontamination. In all cases, the waste would be packaged and certified prior to return shipment to WIPP. In the unlikely event that the external surface contamination is too great to allow safe return and transportation to a shipping site, DOE would take necessary isolation, safety, and decontamination measures. DOE could potentially dispose of any such packages or containers in WIPP, upon appropriate RCRA Part B Permit modification.

The Department proposes to use backfill material, with components added that would minimize the mobility of radionuclides during the repository's post-closure phase, to aid in complying with the requirements of 40 CFR Part 191.13. The mobility of radionuclides, which is determined in part by their solubility in brine, is dependent on the physical and chemical conditions present in the repository, particularly those anticipated as a result of gas generation from the degradation of waste. The purpose of the added component (magnesium oxide) is to react with the brine in such a way that radionuclide solubility and, therefore, the mobility are lowered. Details on the theory behind the current plans for this backfill are described in Appendix D22 of the WIPP RCRA Part B Permit Application (DOE 1996a).

The backfill, in mini sacks of polyethylene or other suitable material, would be manually emplaced in the external voids of each seven-pack unit (a collection of seven drums) just before the seven-pack is positioned on the waste stack. A similar process would be used for standard waste boxes, except that the mini sacks would be hung from the lift clips on the boxes.

For RH-TRU waste to be shipped in the RH-72B cask, the Department would not finalize the waste handling operations procedures until the NRC certifies the RH-72B transportation cask. In general, the procedures would be similar to the sequence described for the CH-TRU waste and the TRUPACT-II. One difference would be that RH-TRU waste would be handled in canisters made of quarter-inch steel with welded lids. Using remote manipulators, the RH-TRU waste canisters

would be removed from the RH-72B casks and placed in a room specially designed for shielding radiation. Subsequent testing operations would be conducted in this room until the canisters would be sent down the waste handling shaft.

3.1.3.3 Emplacement Operations for CH-TRU Waste

At the repository horizon station of the waste handling shaft, specially designed transporters would take the CH-TRU waste pallets from the shaft to the disposal room. Forklifts with a specially designed handling mechanism would then remove the waste from the transport pallets and stack the waste packages three high, leaving up to 1.2 meters (4 feet) of room for ceiling clearance. Each disposal panel would accommodate approximately 81,000 55-gallon drum equivalents (both drums and waste boxes will be used for disposal) equivalent to 16,700 cubic meters (590,000 cubic feet) of CH-TRU waste. DOE would coordinate filling the disposal rooms with RH-TRU waste because the RH-TRU waste would be placed in the walls before filling each room with CH-TRU waste.

In addition, supersacks containing magnesium oxide backfill would be handled and placed with the same technique as used for normal waste handling operations. Once each row of waste units is in place, a layer of six supersacks would be placed on top of them. Finally, magnesium oxide minisacks would be manually stacked on the floor in the space between the waste stack and the panel wall and placed horizontally or vertically. Backfill placed in this manner would remain protected until exposed when sacks are broken during creep closure of the room and compaction of the backfill and waste.

After each panel has been filled, it would be closed using the panel closure system. For the purposes of analyses, the system would be considered passive and consist of either a standard rectangular concrete barrier or an enlarged, tapered concrete barrier. The barrier would be emplaced in both the panel air-intake and air-exhaust tunnels and contact-grouted at the interface between the barrier and the tunnel walls. Contact-grouting involves filling the void spaces. The panel closure system has been designed to add a margin of assurance to limit the migration of hazardous constituents during the 35-year operational and facility closure period and to withstand a potential methane explosion from the accumulation of gas in the panel (see Appendix I of the RCRA Part B Permit Application).

3.1.3.4 Emplacement Operations for RH-TRU Waste

For shielding purposes, the RH-TRU waste canisters would be placed into horizontal boreholes in the walls of the disposal rooms and access tunnels. The horizontal emplacement holes, about 0.9 meters (3 feet) in diameter, would be drilled on 2.4-meter (8-foot) centers to a depth of 4.9 meters (16 feet). Additional holes would be placed in the access tunnels at each end of the disposal rooms. Specially designed insertion equipment would be used to place the RH-TRU waste canisters at the back of the horizontal drill holes and then plug the holes with a massive carbon-steel plug. Once the RH-TRU waste emplacement holes in a disposal room were all used and closed, emplacement of CH-TRU waste would begin (DOE 1995a).

For purposes of analysis, it has been assumed that each RH-TRU waste canister contains three 55-gallon drums containing a total of 0.624 cubic meters (22 cubic feet) of waste. The emplacement volume - which includes the drums of waste, spacers between the drums, and the canister itself - would occupy 0.89 cubic meters (31 cubic feet).

Each disposal panel would accommodate about 730 canisters, equivalent to an emplacement volume of 650 cubic meters (22,950 cubic feet). The SEIS-II analyses are based on the assumption that 7,080 cubic meters (250,000 cubic feet) of RH-TRU waste would be disposed of. The greater volume of RH-TRU waste in SEIS-II than that used for the RCRA Part B Permit Application (DOE 1996a) would be disposed of in the access tunnels, Panels 9 and 10. To account for this difference, these tunnels would each need to be modified to accommodate 1,060 canisters, equivalent to 944 cubic meters (33,000 cubic feet) of waste.

3.1.3.5 Closure and Decommissioning

Under the Proposed Action, WIPP would receive and dispose of TRU waste for 35 years through the year 2033. This is 10 years longer than anticipated in SEIS-I because the Department now has more complete information on the TRU waste inventory and revised estimates of the time needed to treat the waste to meet planning-basis WAC.

DOE would close the repository when WIPP achieves a capacity of 175,600 cubic meters (6.2 million cubic feet) of TRU waste. Final facility closure would include the placement of a

THE PROPOSED ACTION AND THE ADDITIONAL INVENTORY

During the public comment period that followed publication of the Draft SEIS-II in November 1996, stakeholders requested that the Department discuss, as part of the Proposed Action, the impacts of leaving in place or treating and storing the Additional Inventory. The Additional Inventory, as shown in Table 2-3, largely comprises TRU waste disposed of prior to 1970 by burying the waste near the surface. The Department currently has no plans to excavate, treat, and store all of this waste. Such a decision would be made on a site-by-site basis, following RCRA and Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) investigations, and probably following additional NEPA review. The Additional Inventory, therefore, is not a part of the Proposed Action. Nevertheless, in response to stakeholders' requests, Chapter 5 now includes text boxes like this one that present an assessment of human health impacts based on analyses done for the action alternatives and no action alternatives described in Chapter 3 of SEIS-II. The scenarios on which these impacts are based include the following:

- All Additional Inventory would be left as currently stored or buried. The impacts for this scenario would be similar to the Additional Inventory impacts of No Action Alternative 2.
- All Additional Inventory would be excavated, treated to planning-basis WAC, and stored at current locations for approximately 70 years. During the 70 years, the Department would look for a disposal solution. The impacts for this scenario would be very similar to the Additional Inventory treatment and storage impacts presented for Action Alternative 1.
- All Additional Inventory would be excavated, shipped to six thermal treatment facilities, treated, and then stored for approximately 70 years. During the 70 years, the Department would look for a disposal solution. The impacts for this scenario would be very similar to the Additional Inventory treatment and storage impacts presented for Action Alternative 2A.
- All Additional Inventory would be excavated, shipped to four thermal treatment facilities, treated, and then stored for 70 years. The impacts for this scenario would be very similar to the Additional Inventory treatment and storage impacts presented for Action Alternative 2B.

repository sealing system. As explained in more detail in the RCRA Part B Permit Application (DOE 1996a), the planned repository sealing system would consist of natural and engineered barriers within the WIPP repository that would prevent water from entering it and impede gases or brines from migrating out.

Current plans for the shaft sealing system propose completely filling the shaft with engineered materials possessing high density and low permeability. Shaft seal components for that portion of the shaft that is within the Salado Formation would provide the primary barrier by limiting fluid transport along the shaft during and beyond the 10,000-year period. Shaft seal components within the Rustler Formation would limit commingling between brine-bearing members, as required by state regulations. Shaft seal components from the Rustler to the surface would fill the shaft with common materials of high density, consistent with good engineering practice. A synopsis of each component is given below:

- Shaft Station Monolith. At the bottom of each shaft, a salt-saturated concrete monolith would support the local roof. A salt-saturated concrete, called Salado Mass Concrete (SMC), is currently specified and would be placed using a conventional slickline construction procedure where the concrete would be batched at the surface. SMC has been tailored to match site conditions.

- Clay Columns. A sodium bentonite would be used for three compacted clay components in the Salado and Rustler Formations. Although alternative construction specifications are viable, labor-intensive placement of compressed blocks is currently planned because of proven performance. Clay columns would effectively limit brine movement from the time they are placed to beyond the 10,000 year regulatory period.

- Concrete-Asphalt Waterstop Components. Concrete-asphalt waterstop components would be comprised of three elements: an upper concrete plug, a central asphalt waterstop, and a lower concrete plug. Three such components are located within the Salado Formation. These concrete-asphalt waterstop components would provide independent shaft cross-section and disturbed rock zone (DRZ) seals that limit fluid transport, either downward or upward.

- Compacted Salt Column. Each shaft seal would include a column of compacted WIPP salt with 1.5 percent weight water added to the natural material. Construction demonstrations have shown that mine-run WIPP salt could be dynamically compacted to a density equivalent to approximately 90 percent of the average density of intact Salado salt. The remaining void space would be removed through consolidation caused by creep closure.

- Asphalt Column: An asphalt-aggregate mixture currently is specified for the asphalt column, which would bridge the Rustler/Salado contact.

- Concrete Plugs. A concrete plug would be located just above the asphalt column and would be keyed into the surrounding rock.

- Earthen Fill. The upper shaft would be filled with locally available earthen fill. Most of the fill would be dynamically compacted (the same method used to construct the salt column) to a density approximating the surrounding lithologies.

The Department would decommission the site in a manner that would allow for safe, permanent disposition of surface and underground facilities, which would be consistent with the then-applicable regulations. Little or no contamination of facilities would be expected. Equipment and facilities would be decontaminated as necessary. Useable equipment would be removed and surface facilities dismantled. A berm would be constructed around the perimeter of the closure area, which would include 70 hectares (175 acres). The area above the 10 panel equivalents would be 50 hectares (125 acres), the area of the salt pile would be 12 hectares (30 acres), and the area of the surface facilities would be 8 hectares (20 acres). The height of the berm would be sufficient to identify the closure area and impede access. DOE would restore the areas occupied by the salt pile and surface facilities and, if necessary, any of the area overlying the disposal panel area, although surface disturbance of this area would be minimal. This decommissioning period is anticipated to take up to 10 years. Any salt remaining after WIPP closure and construction of the berm would be sold or disposed of in accordance with the Materials Act of 1947.

There are no changes since SEIS-I to the anticipated long-term controls for the WIPP site after the Department closes it, which would include active controls, monitoring, and passive controls. The 100-year active institutional control period would extend through the year 2143, during which the Department would use a fence and an unpaved roadway along the perimeter of the repository surface footprint area (the waste disposal area projected to the surface) to control access. The fence line would be posted with signs that warn of the danger and that state that access by unauthorized persons is prohibited. Routine, periodic patrols and surveillances of the protected area would be conducted as well as periodic inspection and necessary corrective maintenance of the fence, signs, and roadway. In addition, the Department would prohibit drilling within the LWA to preclude inadvertent intrusion into the repository.

The Department would place a number of permanent markers to inform and warn subsequent generations that radioactive waste is buried there. This permanent marker system would be designed to minimize the likelihood of human intrusion. Current plans include markers that would do the following:

- Identify the site
- Relay warning messages
- Use multiple methods for marking the site
- Use multiple means of communications (e.g., language, pictographs, scientific diagrams)
- Use multiple levels of complexity within individual messages on individual marker system elements
- Be constructed of materials with little intrinsic value

Other actions under consideration by DOE are the following:

- Construction of an “information center,” located in the middle of the area, with more information on the type of waste disposed of at WIPP, why the waste is dangerous, and why TRU waste should not be disturbed
- Placement of additional warning messages approximately 6 meters (20 feet) beneath the surface, within the perimeter

- Placement of large permanent magnetic materials and radar reflectors within the berm so that the site could be remotely detected
- Creation of off-site archival records at several local, state, and federal organizations

3.2 ALTERNATIVES

SEIS-II analyzes a total of five alternatives to the Proposed Action, including two no action alternatives. The following sections describe these alternatives. A summary table is presented at the end of this section.

3.2.1 Action and No Action Alternatives

DOE identified the alternatives to the Proposed Action for analyses according to CEQ guidance (46 Federal Register 18026), which indicates that an agency should consider alternatives that are practical or feasible from the technical and economic standpoint and using common sense. Using this guidance and considering the prior LWA requirement that the Department make recommendations for the disposal of all DOE-owned or controlled TRU waste, it is reasonable to examine alternatives that include disposing of all DOE-owned or controlled TRU waste at WIPP. In addition, the CEQ regulations implementing NEPA require a No Action Alternative (40 CFR Part 1502.14 (d)). DOE recognizes that these alternatives may, at least in part, require amendment of existing laws or agreements negotiated with EPA and/or involved states. Nevertheless, under NEPA, DOE is required to consider reasonable alternatives even if they are in conflict with existing law. The fact that DOE is considering these alternatives for the NEPA process should not be construed as meaning that the Department intends to implement any action that would violate the law or violate legally binding agreements negotiated pursuant to law.

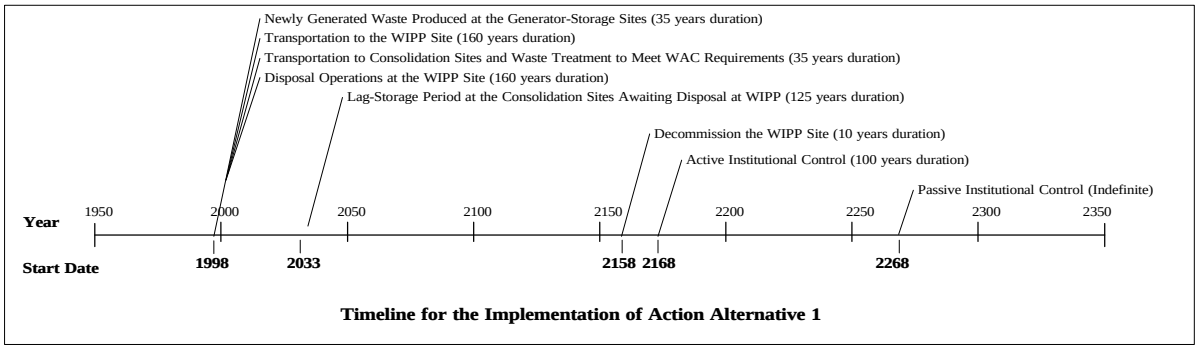
The number of disposal panels required for each alternative is influenced by the 10,000-watt-per-surface-acre design limit on heat load for waste disposed of at WIPP. Consistent with the RCRA Part B Permit Application, an average heat load of 60 watts per RH-TRU waste canister is assumed for the Proposed Action and the alternatives (the actual heat load has been calculated at about 1 watt per canister). Additional mining would be necessary under the action alternatives to distribute the RH-TRU waste as required by the surface acre thermal power limitations. The operational time periods for the action alternatives are driven by current maximum RH-TRU waste emplacement and/or mining rates, which are used only to make the alternatives easily comparable to each other and the Proposed Action. If any of the action alternatives were chosen, waste handling and mining operations could be modified to allow shorter operational time periods, and actual RH-TRU waste heat loads would probably require less mining than that assumed for the alternatives.

3.2.2 Action Alternative 1: Total Inventory (Except PCB-Commingled TRU Waste), Treat to WAC, Dispose of at WIPP

For this alternative, WIPP would accept nearly all TRU waste for disposal. The waste would include the Basic Inventory (with the potential excess RH-TRU waste) plus the Additional Inventory. Only TRU waste commingled with polychlorinated biphenyls (PCB) would not be disposed of at WIPP. The waste would be treated to planning-basis WAC and then shipped to the 10 sites with the largest volumes of waste for consolidation. PCB-commingled waste would

continue to be managed at the generator sites. Table 3-2 presents the CH-TRU waste volumes, and Table 3-3 presents the RH-TRU waste volumes for Action Alternative 1. These tables list the site volume, pretreatment consolidated volume, and post-treatment volume for the Basic Inventory, Additional Inventory, and the combined total (Total Inventory) for each treatment site. DOE could not dispose of some of these additional waste types at WIPP under the current laws and agreements that regulate WIPP. Figure 3-2 shows the flow of TRU waste between sites and shipment to WIPP for Action Alternative 1.

The timeline below presents the approximate schedule for waste disposal activities under Action Alternative 1. Sites would generate waste for 35 years, beginning in 1998. The disposal of TRU waste at WIPP would begin in 1998 and continue for approximately 160 years, ending in 2158. The duration of disposal operations for Action Alternative 1 is based on the time needed to emplace the total volume of RH-TRU waste, assuming a maximum emplacement rate of 356 cubic meters (12,570 cubic feet) per year, a throughput rate of eight RH-72B canisters per week (DOE 1996b), and an operating time of 50 weeks per year. (Section 3.2.2.4 discusses how operations times could be reduced for this alternative.) Decommissioning activities would last for up to 10 years and would be followed by an active institutional control period assumed for analyses to last 100 years, ending in 2268.



Timeline for the Implementation of Action Alternative 1

3.2.2.1 Activities at the Generator-Storage Sites

The activities at the generator-storage sites would be the same as those described for the Proposed Action, except that they would involve approximately twice as much waste based on BIR-3 estimates. The volumes shown in Tables 3-2 and 3-3 reflect the currently stored and projected volumes and the volumes after any packaging and treatment necessary to meet planning-basis WAC. The generator-storage sites would consolidate all CH-TRU waste at 10 treatment sites after treating the waste to meet WAC for subsequent shipment to WIPP. The generator-storage sites would ship RH-TRU waste to four treatment sites for subsequent shipment to WIPP. Waste treatment would occur over 35 years, through the year 2033.

Although all of the TRU waste could be treated and packaged by 2033, much of the waste would be placed in lag storage at the treatment sites awaiting shipment to WIPP. The lag storage would continue for some waste for 125 years. During that period, storage facilities would be constructed and replaced every 50 years. CH-TRU waste awaiting transportation to WIPP would be packaged every 20 years. RH-TRU waste would be stored in canisters made of quarter-inch steel.

Table 3-2
CH-TRU Waste Volumes for Action Alternative 1 [a]

Site [d]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume [b] (cubic meters)			Post-Treatment Disposal Volume [c] (cubic meters)		
	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory
Hanford Site (Hanford)	57,000	63,000	120,000	57,000	63,000	120,000	57,000	63,000	120,000
Los Alamos National Laboratory (LANL)	21,000	14,000	35,000	21,000	14,000	35,000	21,000	14,000	35,000
Idaho National Engineering and Environmental Laboratory (INEEL) [f]	28,000	57,000	85,000	30,000	57,000	86,000	30,000	57,000	87,000
Argonne National Laboratory - West (ANL-W)	1,000	--- [g]	1,000	---	---	---	---	---	---
Argonne National Laboratory - East (ANL-E)	200	---	200	200	---	200	200	---	200
Savannah River Site (SRS)	12,000	4,900	17,000	12,000	4,900	17,000	12,000	4,900	17,000
Rocky Flats Environmental Technology Site (RFETS)	11,000	---	11,000	11,000	---	11,000	17,000	---	17,000
Oak Ridge National Laboratory (ORNL)	1,700	56	1,700	1,800	260	2,100	1,800	260	2,100
Lawrence Livermore National Laboratory (LLNL)	1,200	---	1,200	1,200	---	1,200	1,200	---	1,200
Nevada Test Site (NTS)	630	---	630	630	---	630	630	---	630
Mound Plant (Mound)	300	---	300	300	---	300	340	---	340
Bettis Atomic Power Laboratory (Bettis)	170	---	170	---	---	---	---	---	---
Sandia National Laboratories - Albuquerque (SNL)	17	1	18	---	---	---	---	---	---
Paducah Gaseous Diffusion Plant (PGDP)	8	---	8	---	---	---	---	---	---
U.S. Army Materiel Command (USAMC)	3	---	3	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	2	---	2	---	---	---	---	---	---
University of Missouri Research Reactor (U of Mo)	1	---	1	---	---	---	---	---	---
Ames Laboratory - Iowa State University (Ames)	1	---	1	---	---	---	---	---	---
ARCO Medical Products Company (ARCO)	---	1	1	---	---	---	---	---	---
Lawrence Berkeley Laboratory (LBL)	---	2	2	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	190	190	---	---	---	---	---	---
Total	**135,000**	**139,000**	**273,000**	**135,000**	**138,000**	**273,000**	**143,000**	**138,000**	**281,000**

[a] The inventory for SEIS-II is based on BIR-3,which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Volumes include consolidation of waste as indicated on Figure 3-2.

[c] Post-treatment volumes have been adjusted to meet packaging and transportation criteria.

[d] Sites in boldface were included in SEIS-I.

[e] TRU waste commingled with PCBs is not included.

[f] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

[g] Dashes indicate no waste.

Table 3-3
RH-TRU Waste Volumes for Action Alternative 1 [a]

Site [d]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume [b] (cubic meters)			Post-Treatment Disposal Volume [c] (cubic meters)		
	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory
Hanford Site (Hanford)	29,000	1,000	30,000	29,000	1,000	30,000	42,000	1,500	43,000
Los Alamos National Laboratory (LANL)	230	120	350	230	120	350	330	170	490
Idaho National Engineering and Environmental Laboratory (INEEL) [f]	220	440	660	2,000	440	2,400	2,800	630	3,400
Argonne National Laboratory - West (ANL-W)	1,700	--- [g]	1,700	---	---	---	---	---	---
Oak Ridge National Laboratory (ORNL)	3,100	120	3,200	3,700	2,000	5,600	5,200	2,700	8,000
Bettis Atomic Power Laboratory (Bettis)	9	---	9	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	7	---	7	---	---	---	---	---	---
Battelle Columbus Laboratories (BCL)	580	---	580	---	---	---	---	---	---
Knolls Atomic Power Laboratory (Knolls)	---	80	80	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	1,700	1,700	---	---	---	---	---	---
Total	**35,000**	**3,500**	**39,000**	**35,000**	**3,500**	**39,000**	**50,000**	**5,000**	**55,000**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Volumes include consolidation of waste as indicated on Figure 3-2.

[c] Post-treatment volumes have been adjusted to meet packaging and transportation criteria.

[d] Sites in boldface were included in SEIS-I.

[e] TRU waste commingled with PCBs is not included.

[f] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

[g] Dashes indicate no waste.

3.2.2.2 Transportation Activities

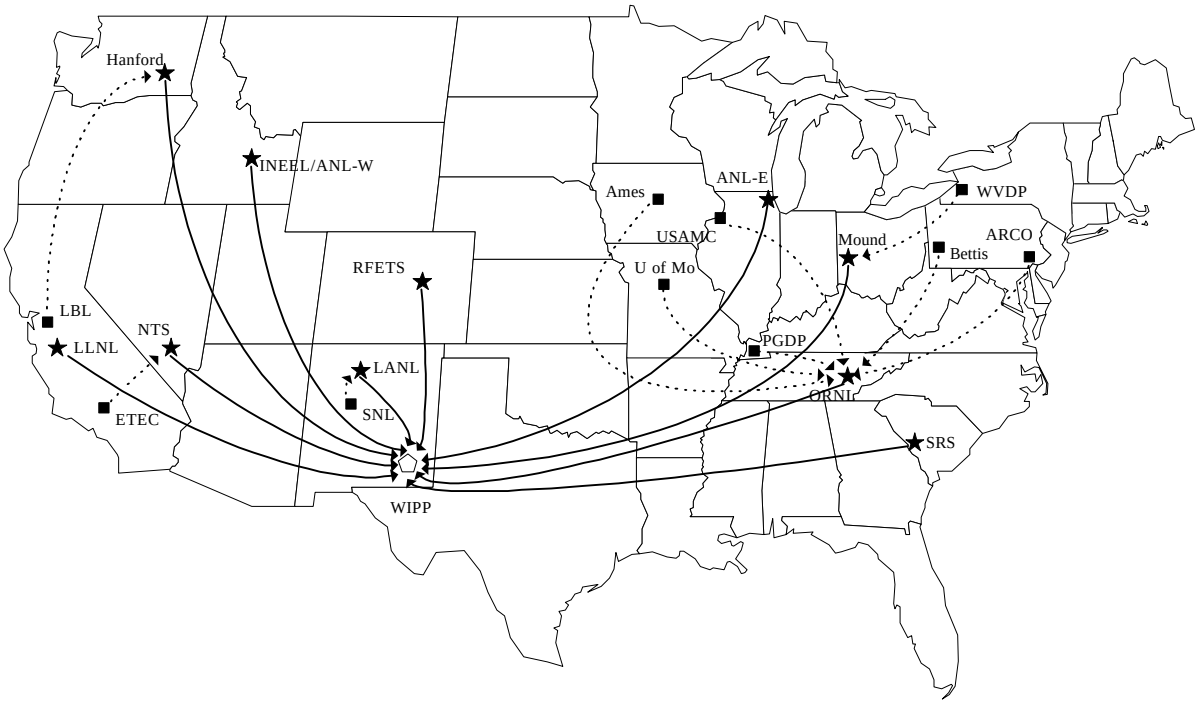
Transportation activities under this alternative would differ from those described for the Proposed Action in the following ways:

- Almost three times as many shipments would be required to ship the CH-TRU and RH-TRU waste to WIPP, due mainly to the additional RH-TRU waste to be shipped to WIPP under Action Alternative 1 (almost eight times more).

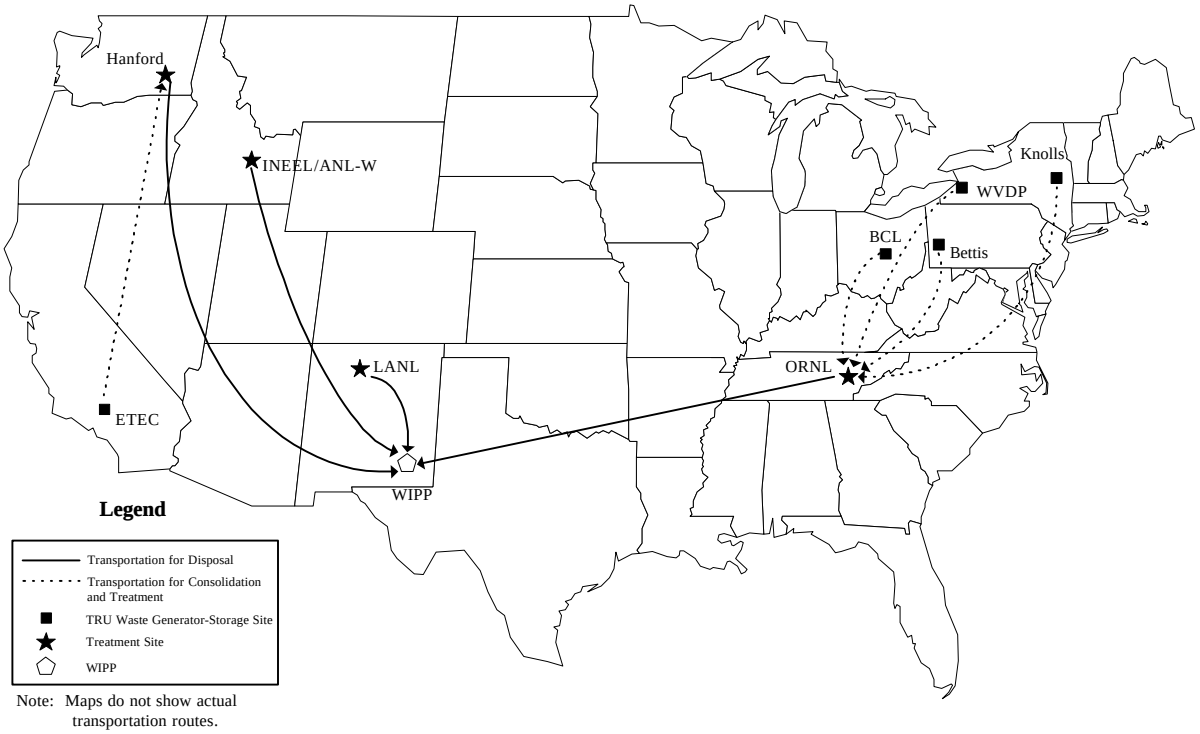
- The period of shipping to WIPP would extend for 160 years, through the year 2158.

- TRU waste may be shipped by truck and by commercial and dedicated rail from the 10 major treatment sites to WIPP. SEIS-II analyses for this alternative include three transportation scenarios. The first scenario uses trucks only, as described under the Proposed Action. The other two scenarios use a mix of commercial rail and truck transportation or dedicated rail and truck transportation. Rail transportation would be used to the maximum extent practicable, and thus the term “maximum rail” is used to indicate

CH-TRU Waste



RH-TRU Waste



Note: Maps do not show actual transportation routes.

Figure 3-2
Movement of Waste for Action Alternative 1 [a]
(For complete names of facilities and waste volumes, see Tables 3-2 and 3-3)

[a] Although Pantex currently has no TRU waste, future decisions by the Department may result in TRU waste generation at Pantex.

the emphasis on rail use. Trucks would be used instead of rail from Los Alamos National Laboratory (LANL) and the Nevada Test Site (NTS) because railroads do not currently exist from those sites. DOE would not build new rail lines. WIPP already has a rail spur leading to the facility.

3.2.2.3 Activities at WIPP

Under Action Alternative 1, excavation operations, TRU waste handling operations at the surface, CH-TRU waste emplacement operations, closure, and decommissioning would be the same as those for the Proposed Action. This alternative would extend the operations time frame to as late as the year 2158, and WIPP would accept a larger total volume of TRU waste. A total of 68 panels would be excavated to accommodate the additional waste, with 17 panels to accommodate CH-TRU and RH-TRU waste and 51 panels for RH-TRU waste only (due to a 10,000 watt-per-acre limit). Any expansion of WIPP capacity beyond current limits would require changes to the LWA and the C&C Agreement, as well as permits to operate WIPP.

As with the Proposed Action, RH-TRU waste canisters would be emplaced in horizontal boreholes in panel walls. Other RH-TRU waste disposal options may be considered, including vertical boreholes or trenches in the floors of disposal rooms. In addition, waste currently considered to be RH-TRU waste at the generator-storage sites may be packaged there to meet CH-TRU waste requirements, not exceeding a dose rate of 200 millirem per hour at the container surface. This waste would then be emplaced as CH-TRU waste at WIPP.

Closure and institutional controls would be the same as those for the Proposed Action, except that due to the additional years of operation, decommissioning and the active institutional control period would extend through the year 2268. A berm would be constructed around the perimeter of the site that is 360 hectares (890 acres), 340 hectares (840 acres) of which lies above the 68 panel-equivalents, 12 hectares (30 acres) of which would be for the salt pile, 8 hectares (20 acres) of which would be for surface facilities. DOE would restore the areas occupied by the salt pile and surface facilities and, if necessary, any of the area overlying the disposal panel equivalents, although surface disturbance of this area would be minimal.

3.2.2.4 Reducing Operation Time

During the public comment period following publication of the Draft SEIS-II, stakeholders stated that the 160-year operations period for Action Alternative 1 was too long and requested that the Department reduce the operations period in some manner. Several commenters requested that the Final SEIS-II include greater detail on how reducing the operation's period would change the impacts presented in Chapter 5 of this document.

DOE has included in Chapter 5 of this document an assessment of impacts should the operation's period be reduced from 160 years to 60 years by constructing additional facilities at the WIPP site and by employing additional excavation and emplacement crews. The assumptions and description of operations presented above would apply, except for the following modifications:

- During the first seven years of the 60-year period, waste would be emplaced in WIPP as described above. In addition, during those seven years, planning and construction of an additional RH-TRU waste handling building would be completed. This new building

would include two RH-TRU waste handling areas. In addition, four new shafts would be constructed, including one waste handling shaft, one salt handling shaft, an air intake shaft, and exhaust shaft. Further NEPA review may need to be conducted, as appropriate, before any new facilities would be built.

- For the final 53 years, all current facilities plus the new facility would be in operation. Two additional excavation crews would be employed, enabling the reduction in operations time from 160 to 60 years. During these 53 years, the emplacement rate would increase from 8 canisters a week to 24 a week. Excavation of new panels would increase from one every two years to three every two years. The same number of panels would be needed.

- In all, an additional 90 people would be employed to operate the new building, its RH-TRU waste operations, and additional excavation and emplacement crews.

- New capital costs would be about $80 million; operating costs would increase by 10 percent.

- All transportation to WIPP would occur over a 60-year period.

3.2.3 Action Alternative 2: Total Inventory (Including PCB-Commingled TRU Waste), Treat Thermally to Meet LDRs, Dispose of at WIPP

For Action Alternative 2, DOE would treat waste with a thermal process designed to meet the Land Disposal Restrictions (LDR) for TRU mixed waste. The analysis performed for this alternative assumes a 65 percent reduction in the volume of waste due to thermal treatment. WIPP would accept all TRU waste for disposal, which would include the Basic Inventory (including the excess RH-TRU waste) plus the Additional Inventory. For this alternative, the Additional Inventory also includes TRU waste commingled with PCBs. DOE could not dispose of some of the waste types included in the Additional Inventory at WIPP under the current laws and agreements that regulate WIPP.

Three different consolidation and treatment subalternatives are considered under Action Alternative 2. These subalternatives are referred to as Action Alternative 2A, 2B, or 2C and vary only in the location of the treatment sites.

- Under Action Alternative 2A, CH-TRU waste would be treated at Hanford, Savannah River Site (SRS), Rocky Flats Environmental Technology Site (RFETS), LANL, and Idaho National Engineering and Environmental Laboratory (INEEL)/Argonne National Laboratory-West (ANL-W). RH-TRU waste would be treated at Hanford and ORNL.

- Under Action Alternative 2B, CH-TRU waste would be treated at Hanford, SRS, and INEEL/ANL-W. RH-TRU waste would be treated at Hanford and ORNL.

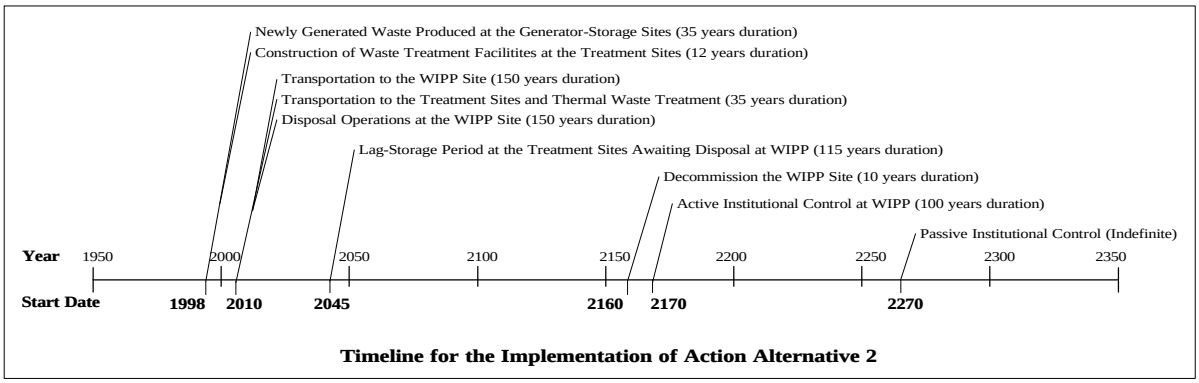
- Under Action Alternative 2C, CH-TRU waste would be treated at WIPP. RH-TRU waste would be treated at Hanford and ORNL.

Table 3-4 presents the CH-TRU waste volumes and Table 3-5 presents the RH-TRU waste volumes for Action Alternative 2A. These tables list the volume by site, pretreatment consolidated volume, and post-treatment volume for the Basic Inventory, Additional Inventory, and Total Inventory. Figure 3-3 shows the flow of TRU waste between sites and shipment to WIPP.

Table 3-6 presents the CH-TRU waste volumes and Table 3-7 presents the RH-TRU waste volumes for Action Alternative 2B. Figure 3-4 shows the flow of TRU waste between sites and shipment to WIPP.

Table 3-8 presents the CH-TRU waste volumes and Table 3-9 presents the RH-TRU waste volumes for Action Alternative 2C. Figure 3-5 shows consolidation of TRU waste and shipment to WIPP. DOE would consolidate and treat CH-TRU waste at WIPP and RH-TRU waste at Hanford and ORNL.

A timeline below presents the approximate schedule for disposal activities under the Action Alternative 2 subalternatives. Sites would generate waste for 35 years, beginning in 1998. It would take 12 years to design and construct the treatment facilities for Action Alternatives 2A, 2B, and 2C. The disposal of TRU waste would begin in 2010 and continue for 150 years, ending in 2160. The disposal operations duration is based on the time needed to excavate the panels and emplace the total volume of RH-TRU waste, assuming a maximum emplacement rate of 356 cubic meters (12,570 cubic feet) per year, a throughput rate of eight RH-72B canisters per week (DOE 1996b), and an operating time of 50 weeks per year. Decommissioning activities would last for up to 10 years and would be followed by an active institutional control period assumed for analyses to last 100 years, ending in 2270. (See Section 3.2.3.4 for discussion of how time periods could be reduced for this alternative.)



Timeline for the Implementation of Action Alternative 2

3.2.3.1 Activities at the Generator-Storage Sites

Under this alternative, the generator-storage sites would prepare twice as much waste as under the Proposed Action, and the waste would be treated by a thermal process to meet the RCRA LDRs. Thermal treatment may involve a vitrification process. The process would vaporize organic matter, thereby reducing the total volume of waste. A vitrification process would add silicon-based materials that would result in a glass-like product. The volumes shown in Tables 3-4 through 3-9 reflect the currently stored or projected volumes and the treatment method. To be conservative, it has been assumed that all waste treatment facilities would be designed and constructed over a period of 12 years and would be ready for operation in the year 2010. (Some sites may be able to

Table 3-4
CH-TRU Waste Volumes for Action Alternative 2A [a]

Site [d]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume [b] (cubic meters)			Post-Treatment Disposal Volume [c] (cubic meters)		
	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory
Hanford Site (Hanford)	57,000	63,000	120,000	59,000	63,000	122,000	21,000	22,000	43,000
Los Alamos National Laboratory (LANL)	21,000	14,000	35,000	21,000	14,000	35,000	7,400	4,900	12,000
Idaho National Engineering and Environmental Laboratory (INEEL) [f]	28,000	57,000	85,000	30,000	57,000	87,000	10,000	31,000	41,000
Argonne National Laboratory - West (ANL-W)	1,000	--- [g]	1,000	---	---	---	---	---	---
Argonne National Laboratory-East (ANL-E)	200	---	200	---	---	---	---	---	---
Savannah River Site (SRS)	12,000	4,900	17,000	14,000	5,000	20,000	5,000	1,800	6,800
Rocky Flats Environmental Technology Site (RFETS)	11,000	---	11,000	11,000	---	11,000	3,800	---	3,800
Oak Ridge National Laboratory (ORNL)	1,700	66	1,700	---	---	---	---	---	---
Lawrence Livermore National Laboratory (LLNL)	1,200	---	1,200	---	---	---	---	---	---
Nevada Test Site (NTS)	630	---	630	---	---	---	---	---	---
Mound Plant (Mound)	300	20	320	---	---	---	---	---	---
Bettis Atomic Power Laboratory (Bettis)	170	---	170	---	---	---	---	---	---
Sandia National Laboratories - Albuquerque (SNL)	17	1	18	---	---	---	---	---	---
Paducah Gaseous Diffusion Plant (PGDP)	8	---	8	---	---	---	---	---	---
U.S. Army Materiel Command (USAMC)	3	---	3	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	2	---	2	---	---	---	---	---	---
University of Missouri Research Reactor (U of Mo)	1	---	1	---	---	---	---	---	---
Ames Laboratory - Iowa State University (Ames)	1	---	1	---	---	---	---	---	---
ARCO Medical Products Company (ARCO)	---	1	1	---	---	---	---	---	---
Lawrence Berkeley Laboratory (LBL)	---	2	2	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	190	190	---	---	---	---	---	---
Total	**135,000**	**139,000**	**274,000**	**135,000**	**139,000**	**274,000**	**47,000**	**60,000**	**107,000**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Volumes include consolidation of waste as indicated on Figure 3-3.

[c] Post-treatment volumes have been adjusted to meet packaging and transportation criteria.

[d] Sites in boldface were included in SEIS-I.

[e] TRU waste commingled with PCBs is included.

[f] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

[g] Dashes indicate no waste.

Table 3-5
RH-TRU Waste Volumes for Action Alternative 2A [a]

Site [d]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume [b] (cubic meters)			Post-Treatment Disposal Volume [c] (cubic meters)		
	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory
Hanford Site (Hanford)	29,000	1,000	30,000	32,000	1,600	33,000	16,000	920	17,000
Los Alamos National Laboratory (LANL)	230	120	350	--- [f]	---	---	---	---	---
Idaho National Engineering and Environmental Laboratory (INEEL) [g]	220	440	660	---	---	---	---	---	---
Argonne National Laboratory - West (ANL-W)	1,700	---	1,700	---	---	---	---	---	---
Oak Ridge National Laboratory (ORNL)	3,100	120	3,200	3,700	1,900	5,600	1,800	960	2,800
Bettis Atomic Power Laboratory (Bettis)	9	---	9	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	7	---	7	---	---	---	---	---	---
Battelle Columbus Laboratories (BCL)	580	---	580	---	---	---	---	---	---
Knolls Atomic Power Laboratory (Knolls)	---	81	81	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	1,700	1,700	---	---	---	---	---	---
Total	**35,000**	**3,500**	**39,000**	**35,000**	**3,500**	**39,000**	**18,000**	**1,900**	**19,000**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Volumes include consolidation of waste as indicated on Figure 3-3.

[c] Post-treatment volumes have been adjusted to meet packaging and transportation criteria.

[d] Sites in boldface were included in SEIS-I.

[e] TRU waste commingled with PCBs is included.

[f] Dashes indicate no waste.

[g] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

procure such services earlier.) Waste treatment would occur over 35 years, through the year 2045, and lag storage of the TRU waste awaiting shipment (under Action Alternatives 2A and 2B) would occur for 115 years, also through the year 2160. Under these alternatives, lag storage would be required due to the rate at which the panels could be excavated. The lag storage would be similar to that described in Section 3.2.2.1.

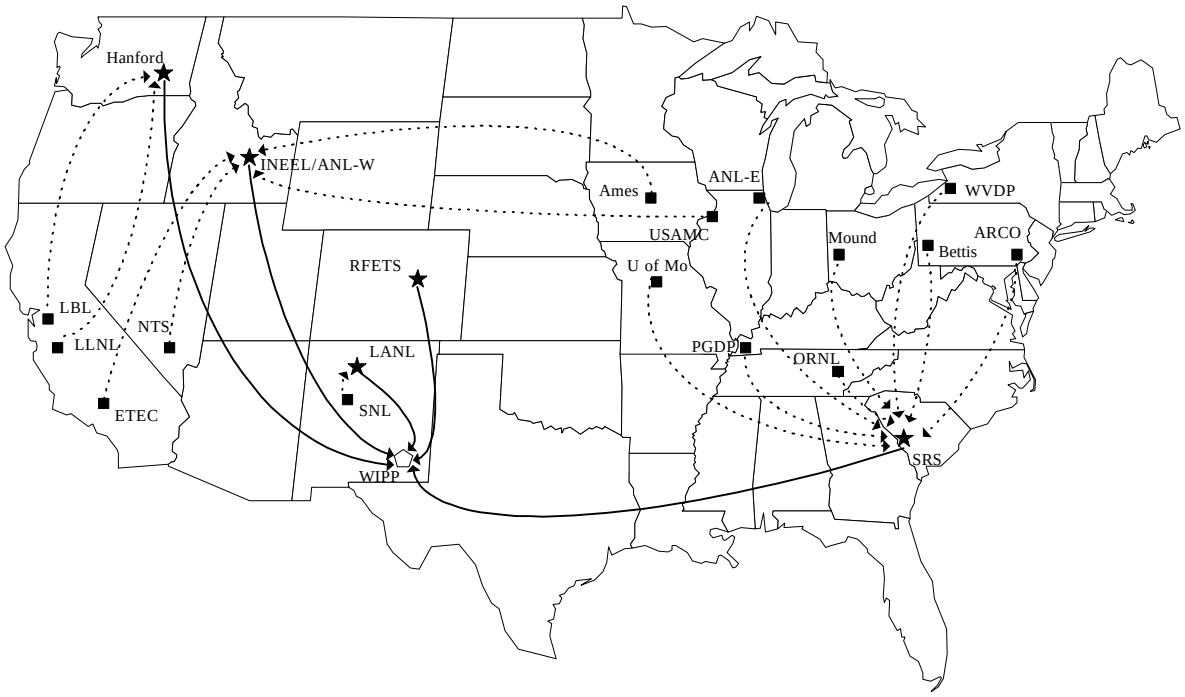
3.2.3.2 Transportation Activities

Transportation activities under this alternative would differ from those described for the Proposed Action in the following ways:

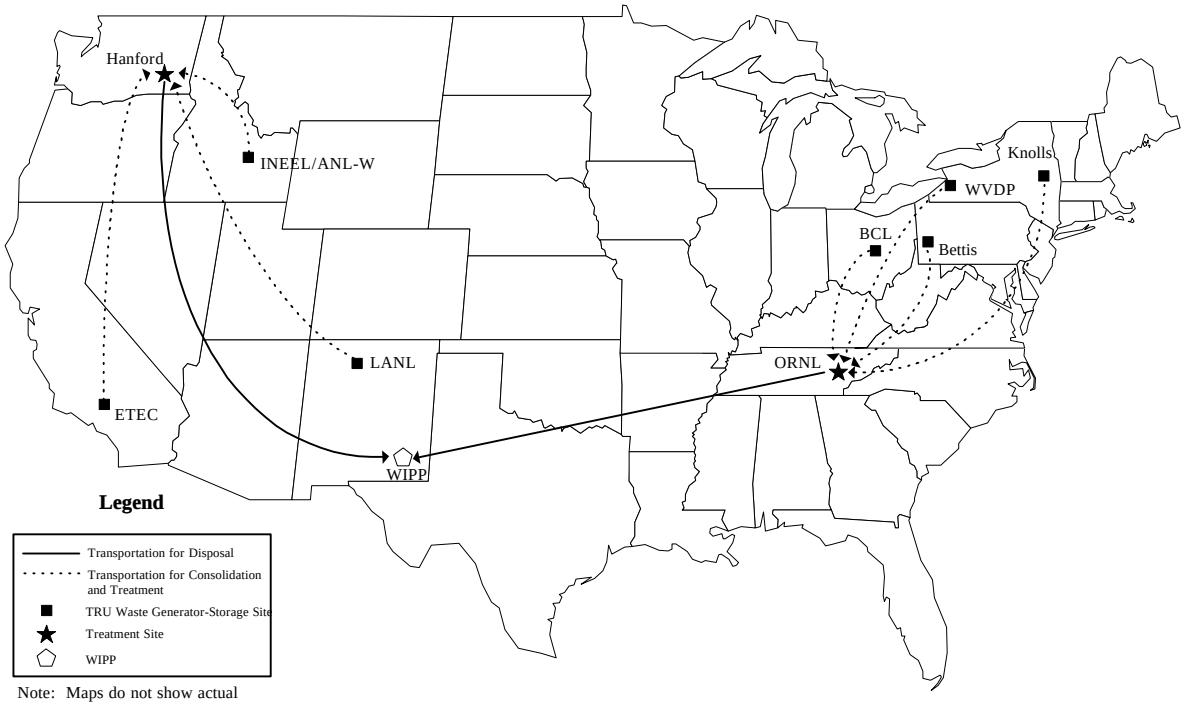
- The period of shipping to WIPP would continue for 150 years, through the year 2160 (compared to 35 years under the Proposed Action).

- SEIS-II analyses for this alternative include three transportation scenarios. The first scenario uses only trucks, as described under the Proposed Action. The other two use a

CH-TRU Waste



RH-TRU Waste



Note: Maps do not show actual transportation routes.

Figure 3-3
Movement of Waste for Action Alternative 2A [a]
(For complete names of facilities and waste volumes, see Tables 3-4 and 3-5)

[a] Although Pantex currently has no TRU waste, future decisions by the Department may result in TRU waste generation at Pantex.

Table 3-6
CH-TRU Waste Volumes for Action Alternative 2B [a]

Site [d]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume [b] (cubic meters)			Post-Treatment Disposal Volume [c] (cubic meters)		
	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory
Hanford Site (Hanford)	57,000	63,000	120,000	59,000	63,000	122,000	21,000	22,000	43,000
Los Alamos National Laboratory (LANL)	21,000	14,000	35,000	--- [f]	---	---	---	---	---
Idaho National Engineering and Environmental Laboratory (INEEL) [g]	28,000	57,000	85,000	62,000	71,000	133,000	22,000	36,000	57,000
Argonne National Laboratory-West (ANL-W)	1,000	---	1,000	---	---	---	---	---	---
Argonne National Laboratory - East (ANL-E)	200	---	200	---	---	---	---	---	---
Savannah River Site (SRS)	12,000	4,900	17,000	14,000	5,200	20,000	5,000	1,800	6,800
Rocky Flats Environmental Technology Site (RFETS)	11,000	---	11,000	---	---	---	---	---	---
Oak Ridge National Laboratory (ORNL)	1,700	66	1,700	---	---	---	---	---	---
Lawrence Livermore National Laboratory (LLNL)	1,200	---	1,200	---	---	---	---	---	---
Nevada Test Site (NTS)	630	---	630	---	---	---	---	---	---
Mound Plant (Mound)	300	19	320	---	---	---	---	---	---
Bettis Atomic Power Laboratory (Bettis)	170	---	170	---	---	---	---	---	---
Sandia National Laboratories - Albuquerque (SNL)	17	1	18	---	---	---	---	---	---
Paducah Gaseous Diffusion Plant (PGDP)	8	---	8	---	---	---	---	---	---
U.S. Army Materiel Command (USAMC)	3	---	3	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	2	---	2	---	---	---	---	---	---
University of Missouri Research Reactor (U of Mo)	1	---	1	---	---	---	---	---	---
Ames Laboratory - Iowa State University (Ames)	1	---	1	---	---	---	---	---	---
ARCO Medical Products Company (ARCO)	---	1	1	---	---	---	---	---	---
Lawrence Berkeley Laboratory (LBL)	---	2	2	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	190	190	---	---	---	---	---	---
Total	**135,000**	**139,000**	**274,000**	**135,000**	**139,000**	**274,000**	**47,000**	**60,000**	**107,000**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Volumes include consolidation of waste as indicated on Figure 3-4.

[c] Post-treatment volumes have been adjusted to meet packaging and transportation criteria.

[d] Sites in boldface were included in SEIS-I.

[e] TRU waste commingled with PCBs is included.

[f] Dashes indicate no waste.

[g] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

Table 3-7
RH-TRU Waste Volumes for Action Alternative 2B [a]

Site [d]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume [b] (cubic meters)			Post-Treatment Disposal Volume [c] (cubic meters)		
	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory
Hanford Site (Hanford)	29,000	1,000	30,000	32,000	1,600	33,000	16,000	920	17,000
Los Alamos National Laboratory (LANL)	230	120	350	---[f]	---	---	---	---	---
Idaho National Engineering and Environmental Laboratory (INEEL) [g]	220	440	660	---	---	---	---	---	---
Argonne National Laboratory-West (ANL-W)	1,700	---	1,700	---	---	---	---	---	---
Oak Ridge National Laboratory (ORNL)	3,100	120	3,200	3,700	1,900	5,600	1,800	960	2,800
Bettis Atomic Power Laboratory (Bettis)	9	---	9	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	7	---	7	---	---	---	---	---	---
Battelle Columbus Laboratories (BCL)	580	---	580	---	---	---	---	---	---
Knolls Atomic Power Laboratory (Knolls)	---	81	81	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	1,700	1,700	---	---	---	---	---	---
Total	**35,000**	**3,500**	**39,000**	**35,000**	**3,500**	**39,000**	**18,000**	**1,900**	**19,000**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Volumes include consolidation of waste as indicated on Figure 3-4.

[c] Post-treatment volumes have been adjusted to meet packaging and transportation criteria.

[d] Sites in boldface were included in SEIS-I.

[e] TRU waste commingled with PCBs is included.

[f] Dashes indicate no waste.

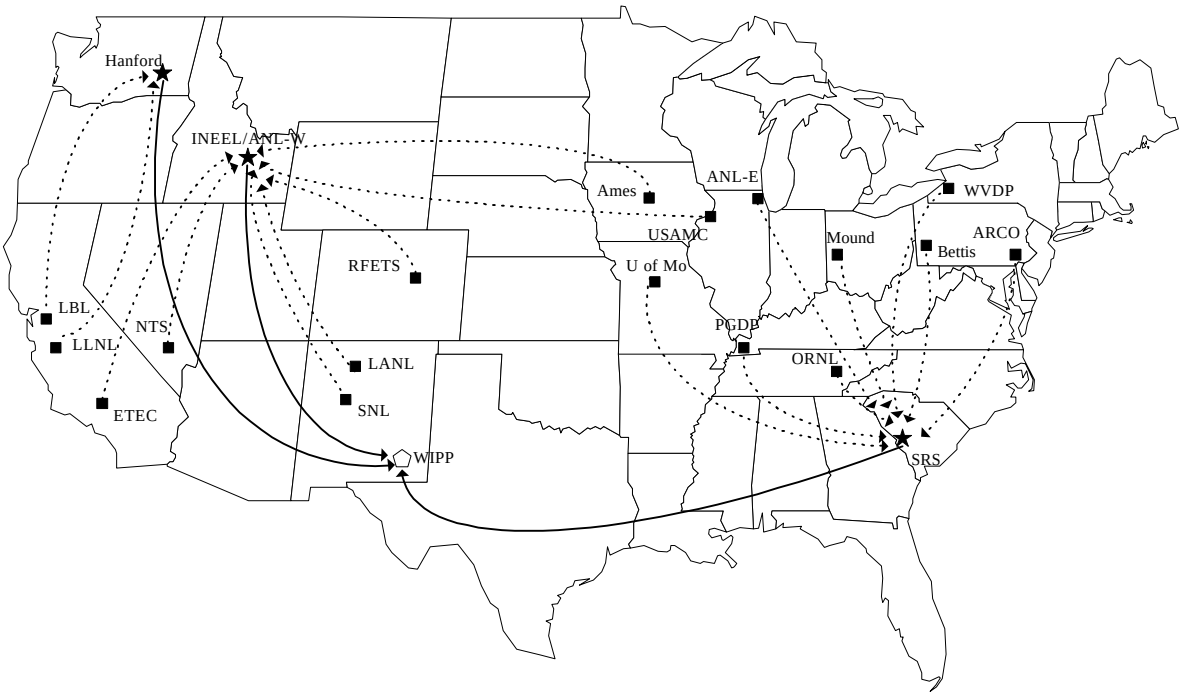
[g] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

mix of maximum commercial rail and truck transportation or maximum dedicated rail and truck transportation, as described in Section 3.2.2.2. WIPP already has a rail spur leading to the facility. Because little storage is permitted at WIPP, all of the transportation scenarios would be spread over the 150-year shipping period.

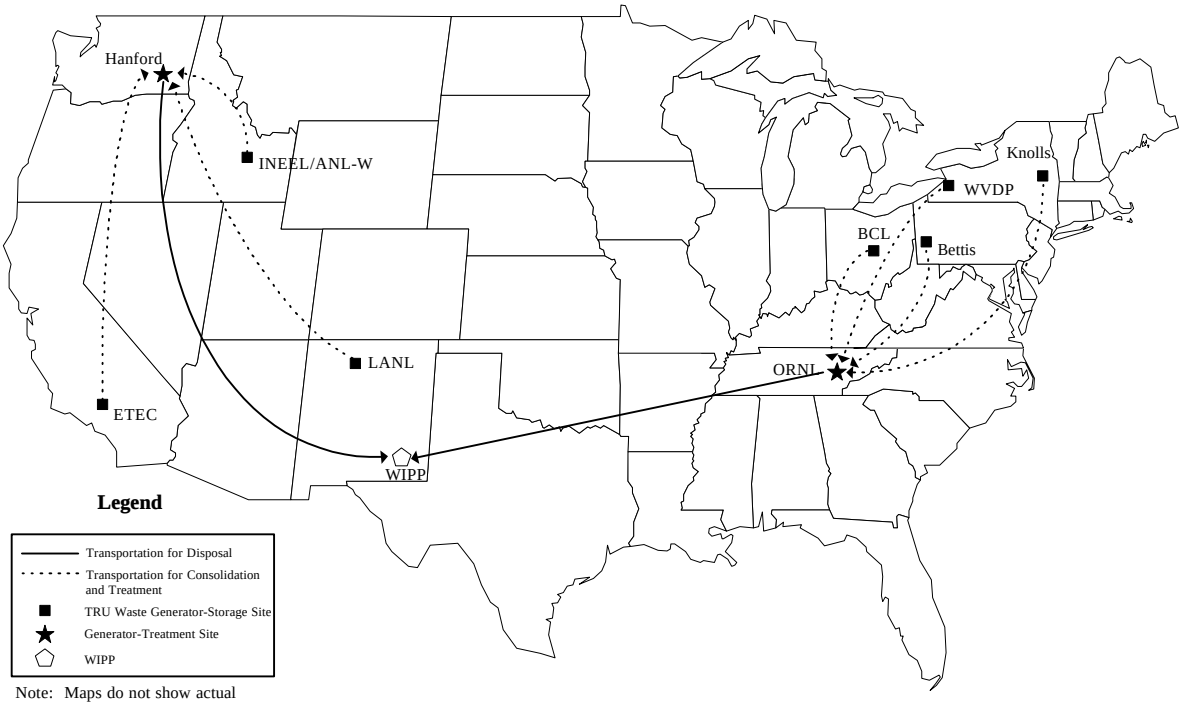
3.2.3.3 Activities at WIPP

Under Action Alternative 2, excavation operations, TRU waste handling operations at the surface, CH-TRU waste emplacement operations, closure, and decommissioning would be similar to the Proposed Action. However, this alternative would extend the operations time frame to as late as the year 2160 even though the overall emplaced waste volume would be smaller than that under all of the other alternatives. As noted above, thermal treatment results in an overall volume reduction of 65 percent. The same quantity of radionuclides would now be present in 35 percent of the original volume; therefore, radionuclide concentration and thermal power generation would increase by a factor of approximately three. Because of the increased thermal power output, CH-TRU waste and RH-TRU waste would be placed in separate panels to meet the WIPP design specifications for thermal power. About 12 panels would be required for CH-TRU waste disposal

CH-TRU Waste



RH-TRU Waste



Note: Maps do not show actual transportation routes.

Figure 3-4
Movement of Waste for Action Alternative 2B [a]
(For complete names of facilities and waste volumes, see Tables 3-6 and 3-7)

[a] Although Pantex currently has no TRU waste, future decisions by the Department may result in TRU waste generation at Pantex.

Table 3-8
CH-TRU Waste Volumes for Action Alternative 2C [a]

Site [b]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume (cubic meters)			Post-Treatment Disposal Volume (cubic meters)		
	Basic Inventory	Additional Inventory [c]	Total Inventory	Basic Inventory	Additional Inventory [c]	Total Inventory	Basic Inventory	Additional Inventory [c]	Total Inventory
Hanford Site (Hanford)	57,000	63,000	120,000	--- [d]	---	---	---	---	---
Los Alamos National Laboratory (LANL)	21,000	14,000	35,000	---	---	---	---	---	---
Idaho National Engineering and Environmental Laboratory (INEEL) [e]	28,000	57,000	85,000	---	---	---	---	---	---
Argonne National Laboratory-West (ANL-W)	1,000	---	1,000	---	---	---	---	---	---
Argonne National Laboratory-East (ANL-E)	200	---	200	---	---	---	---	---	---
Savannah River Site (SRS)	12,000	4,900	17,000	---	---	---	---	---	---
Rocky Flats Environmental Technology Site (RFETS)	11,000	---	11,000	---	---	---	---	---	---
Oak Ridge National Laboratory(ORNL)	1,700	66	1,700	---	---	---	---	---	---
Lawrence Livermore National Laboratory (LLNL)	1,200	---	1,200	---	---	---	---	---	---
Nevada Test Site (NTS)	630	---	630	---	---	---	---	---	---
Mound Plant (Mound)	300	19	320	---	---	---	---	---	---
Bettis Atomic Power Laboratory (Bettis)	170	---	170	---	---	---	---	---	---
Sandia National Laboratories - Albuquerque (SNL)	17	1	18	---	---	---	---	---	---
Paducah Gaseous Diffusion Plant (PGDP)	8	---	8	---	---	---	---	---	---
U.S. Army Materiel Command (USAMC)	3	---	3	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	2	---	2	---	---	---	---	---	---
University of Missouri Research Reactor (U of Mo)	1	---	1	---	---	---	---	---	---
Ames Laboratory - Iowa State University (Ames)	1	---	1	---	---	---	---	---	---
ARCO Medical Products Company (ARCO)	---	1	1	---	---	---	---	---	---
Lawrence Berkeley Laboratory (LBL)	---	2	2	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	190	190	---	---	---	---	---	---
WIPP [f]	---	---	---	135,000	139,000	274,000	47,000	60,000	107,000
Total	**135,000**	**139,000**	**274,000**	**135,000**	**139,000**	**274,000**	**47,000**	**60,000**	**107,000**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Sites in boldface were included in SEIS-I.

[c] TRU waste commingled with PCBs is included.

[d] Dashes indicate no waste.

[e] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

[f] TRU waste is consolidated and treated at WIPP.

Table 3-9
RH-TRU Waste Volumes for Action Alternative 2C [a]

Site [d]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume [b] (cubic meters)			Post-Treatment Disposal Volume [c] (cubic meters)		
	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory
Hanford Site (Hanford)	29,000	1,000	30,000	32,000	1,600	33,000	16,000	920	17,000
Los Alamos National Laboratory (LANL)	230	120	350	--- [f]	---	---	---	---	---
Idaho National Engineering and Environmental Laboratory (INEEL) [g]	220	440	660	---	---	---	---	---	---
Argonne National Laboratory-West (ANL-W)	1,700	---	1,700	---	---	---	---	---	---
Oak Ridge National Laboratory (ORNL)	3,100	120	3,200	3,700	1,900	5,600	1,800	960	2,800
Bettis Atomic Power Laboratory (Bettis)	9	---	9	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	7	---	7	---	---	---	---	---	---
Battelle Columbus Laboratories (BCL)	580	---	580	---	---	---	---	---	---
Knolls Atomic Power Laboratory (Knolls)	---	81	81	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	1,700	1,700	---	---	---	---	---	---
Total	**35,000**	**3,500**	**39,000**	**35,000**	**3,500**	**39,000**	**18,000**	**1,900**	**19,000**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Volumes include consolidation of waste as indicated on Figure 3-5.

[c] Post-treatment volumes have been adjusted to meet packaging and transportation criteria.

[d] Sites in boldface were included in SEIS-II.

[e] TRU waste commingled with PCBs is included.

[f] Dashes indicate no waste.

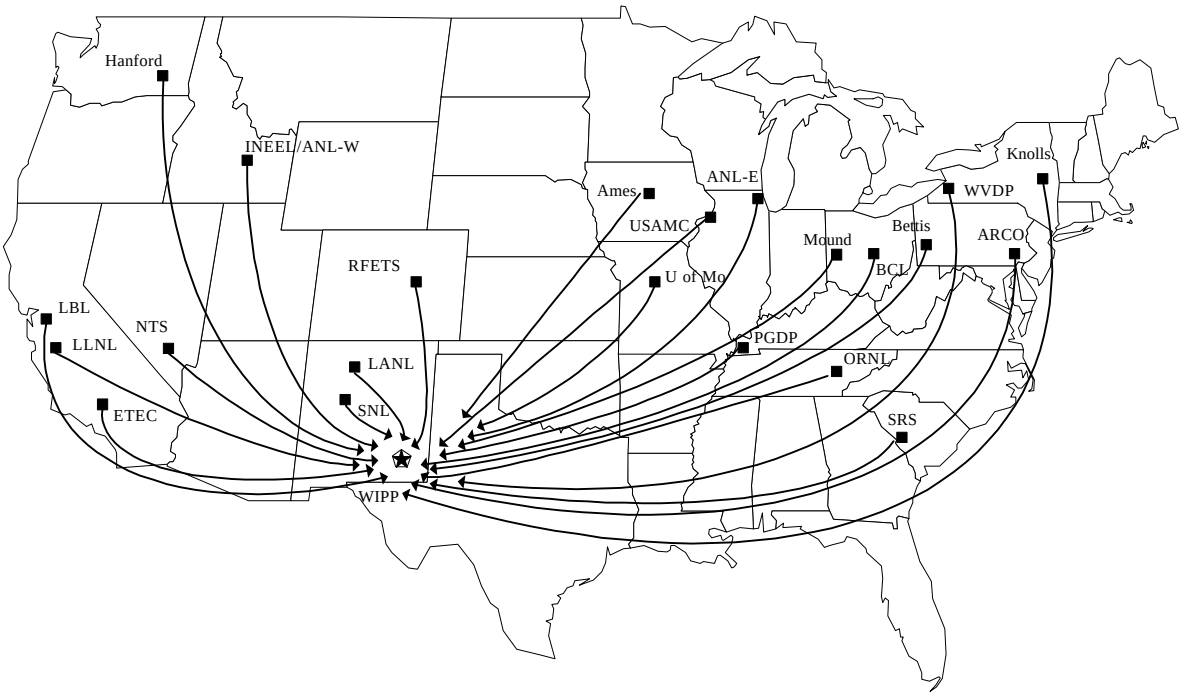
[g] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

and about 63 panels would be required for RH-TRU waste disposal, 75 panels total. The time required for excavation of 75 panels, at a rate of two years per panel, is the basis for the 150-year operation period. Any expansion of WIPP capacity would require changes to the LWA and the C&C Agreement.

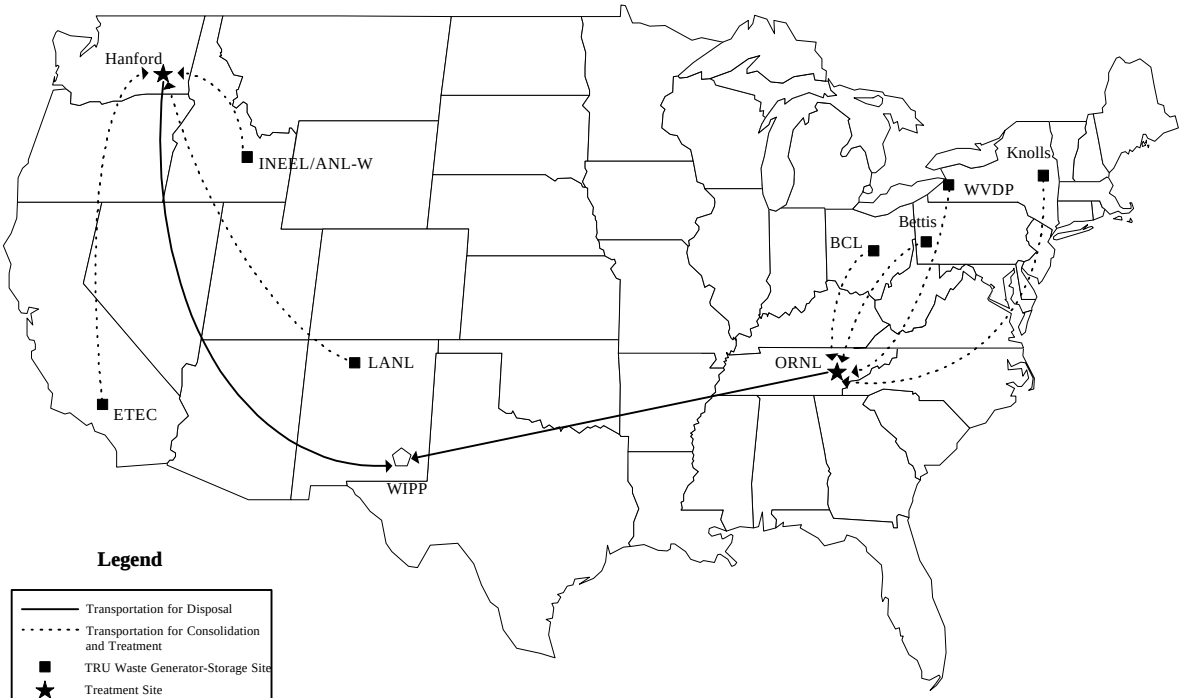
As in the Proposed Action, RH-TRU waste canisters would be emplaced in horizontal boreholes in the walls of the panels. Because of the increased volume of RH-TRU waste, other RH-TRU waste disposal options may be considered, including horizontal boreholes that could accommodate two canisters and vertical boreholes or trenches in the floors of disposal rooms.

Closure and institutional controls would be the same as those for the Proposed Action except that due to the additional years of operation, the decommissioning and active institutional control period would extend through the year 2270. A berm would be constructed around the perimeter of the site, which would include 395 hectares (976 acres), 375 hectares (927 acres) of which lies above the 75 panel equivalents, 12 hectares (30 acres) of which is for the salt pile, and 8 hectares

CH-TRU Waste



RH-TRU Waste



Note: Maps do not show actual transportation routes.

Figure 3-5
Movement of Waste for Action Alternative 2C [a]
(For complete names of facilities and waste volumes, see Tables 3-8 and 3-9)

[a] Although Pantex currently has no TRU waste, future decisions by the Department may result in TRU waste generation at Pantex.

(20 acres) of which is for surface facilities. DOE would restore the areas occupied by the salt pile and surface facilities, and, if necessary, any of the area overlying the disposal panel equivalents, although surface disturbance of this area would be minimal.

3.2.3.4 Reducing Operation Time

The overall operation period – including 12 years of construction for offsite thermal treatment facilities (at Hanford, SRS, RFETS, LANL, INEEL, or ORNL) - would be 150 years for all Action Alternative 2 subalternatives. Largely, though, the long operation period is due to the number of panels needed to meet the thermal limit per acre for the RH-TRU waste and an assumption that only one panel would be excavated every two years. This assumption was made to enable all of the SEIS-II alternatives to be easily comparable.

As with Action Alternative 1, stakeholders requested a more detailed understanding of how impacts would change should the Department attempt to shorten the operation time. In response, Chapter 5 of this document includes an assessment of how impacts would change if the excavation of panels were increased to reduce the total operation period to 70 years. For the purposes of the assessment, the discussion of assumptions and description of operations presented above for all of the Action Alternative 2 subalternatives would apply, with the following exceptions:

- WIPP would remain as currently operated for 12 years while thermal treatment facilities were designed and constructed. The 12 years were conservatively estimated; some facilities may begin treatment sooner. No new buildings would be constructed at WIPP because the volume of waste would be reduced by the thermal treatment, but during the first 12 years three additional shafts would be constructed to enable faster excavation and emplacement in the repository. These shafts would be an additional salt handling shaft, an additional air intake shaft, and an exhaust shaft. Further NEPA review may need to be conducted, as appropriate, before any new facilities would be built.

- Two additional excavation crews would be employed during emplacement operations. These two crews would result in approximately 10 additional WIPP employees. The two crews would enable DOE to increase the excavation rate to three panels every two years and increase the emplacement rate from 8 canisters a week to 24 canisters a week. Overall, the two crews would reduce the period of disposal operations at WIPP from 150 years to 58 years.

- Transportation to WIPP would occur during 58 years.

- Capital construction costs for the three shafts would total $24 million; annual operating costs would remain essentially the same.

3.2.4 Action Alternative 3: Total Inventory (Except PCB-Commingled Waste), Treat by Shred and Grout, Dispose of at WIPP

Action Alternative 3 would involve treating the waste with a shred and grout process. This process would increase the volume by 20 percent. For this alternative, WIPP would accept for disposal all TRU waste, which would include the Basic Inventory and the Additional Inventory without PCB-commingled waste. DOE could not dispose of some of the Additional Inventory waste types at WIPP under the current laws and agreements that regulate WIPP. Table 3-10 presents the

Table 3-10
CH-TRU Waste Volumes for Action Alternative 3 [a]

Site [d]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume [b] (cubic meters)			Post-Treatment Disposal Volume [c] (cubic meters)		
	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory
Hanford Site (Hanford)	57,000	63,000	120,000	59,000	63,000	121,000	70,000	75,000	146,000
Los Alamos National Laboratory (LANL)	21,000	14,000	35,000	21,000	14,000	35,000	25,000	17,000	42,000
Idaho National Engineering and Environmental Laboratory (INEEL) [f]	28,000	57,000	85,000	30,000	57,000	86,000	37,000	68,000	105,000
Argonne National Laboratory - West (ANL-W)	1,000	--- [g]	1,000	---	---	---	---	---	---
Argonne National Laboratory - East (ANL-E)	200	---	200	---	---	---	---	---	---
Savannah River Site (SRS)	12,000	4,900	17,000	14,000	5,000	20,000	17,000	6,200	23,000
Rocky Flats Environmental Technology Site (RFETS)	11,000	---	11,000	11,000	---	11,000	19,000	---	19,000
Oak Ridge National Laboratory (ORNL)	1,700	66	1,700	---	---	---	---	---	---
Lawrence Livermore National Laboratory (LLNL)	1,200	---	1,200	---	---	---	---	---	---
Nevada Test Site (NTS)	630	---	630	---	---	---	---	---	---
Mound Plant (Mound)	300	---	300	---	---	---	---	---	---
Bettis Atomic Power Laboratory (Bettis)	170	---	170	---	---	---	---	---	---
Sandia National Laboratories - Albuquerque (SNL)	17	1	18	---	---	---	---	---	---
Paducah Gaseous Diffusion Plant (PGDP)	8	---	8	---	---	---	---	---	---
U.S. Army Materiel Command (USAMC)	3	---	3	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	2	---	2	---	---	---	---	---	---
University of Missouri Research Reactor (U of Mo)	1	---	1	---	---	---	---	---	---
Ames Laboratory - Iowa State University (Ames)	1	---	1	---	---	---	---	---	---
ARCO Medical Products Company (ARCO)	---	1	1	---	---	---	---	---	---
Lawrence Berkeley Laboratory (LBL)	---	2	2	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	190	190	---	---	---	---	---	---
Total	**135,000**	**138,000**	**273,000**	**135,000**	**138,000**	**273,000**	**168,000**	**166,000**	**334,000**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Volumes include consolidation of waste as indicated on Figure 3-6.

[c] Post-treatment volumes have been adjusted to meet packaging and transportation criteria.

[d] Sites in boldface were included in SEIS-I.

[e] TRU waste commingled with PCBs is not included.

[f] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

[g] Dashes indicate no waste.

CH-TRU waste volumes and Table 3-11 presents the RH-TRU waste volumes for Action Alternative 3. Figure 3-6 shows the flow of TRU waste between sites and shipment to WIPP. DOE would consolidate and treat CH-TRU waste at Hanford, INEEL, LANL, and SRS (RFETS would treat only its own waste). RH-TRU waste would be consolidated and treated at Hanford and ORNL.

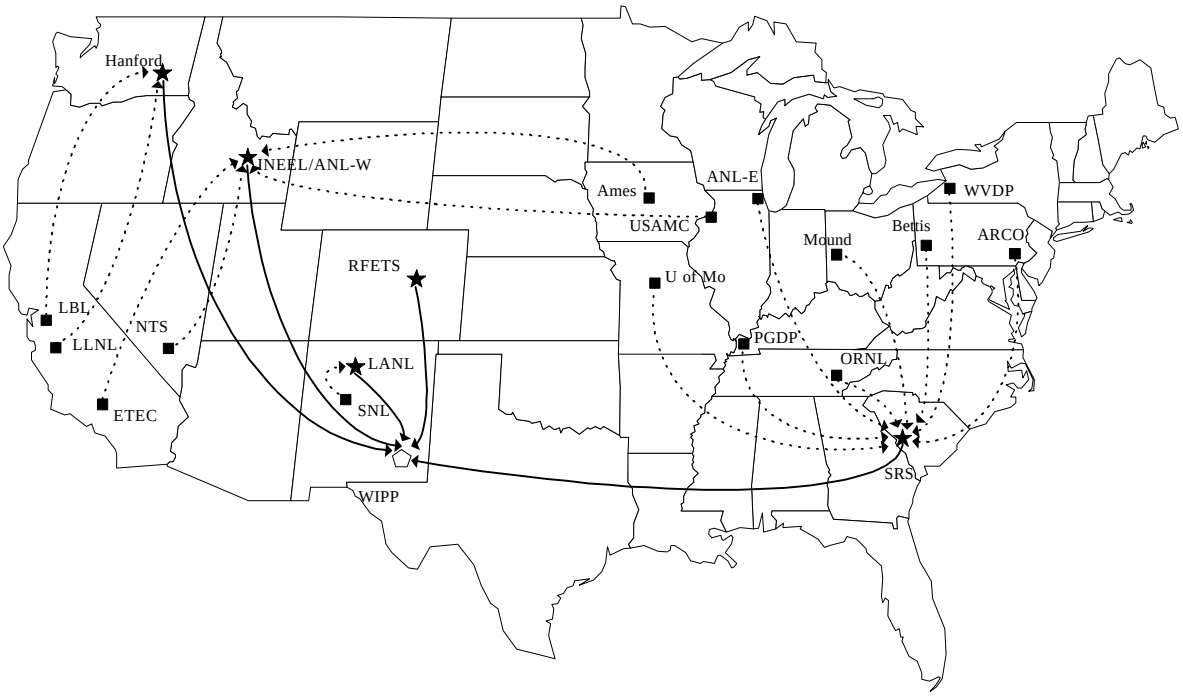
Table 3-11
RH-TRU Waste Volumes for Action Alternative 3 [a]

Site [d]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume [b] (cubic meters)			Post-Treatment Disposal Volume [c] (cubic meters)		
	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory
Hanford Site (Hanford)	29,000	1,000	30,000	32,000	1,600	33,000	54,000	2,700	57,000
Los Alamos National Laboratory. (LANL)	230	120	350	--- [f]	---	---	---	---	---
Idaho National Engineering and Environmental Laboratory (INEEL) [g]	220	440	660	---	---	---	---	---	---
Argonne National Laboratory - West (ANL-W)	1,700	---	1,700	---	---	---	---	---	---
Oak Ridge National Laboratory (ORNL)	3,100	120	3,200	3,700	1,900	5,600	6,300	3,300	10,000
Bettis Atomic Power Laboratory (Bettis)	9	---	9	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	7	---	7	---	---	---	---	---	---
Battelle Columbus Laboratories (BCL)	580	---	580	---	---	---	---	---	---
Knolls Atomic Power Laboratory (Knolls)	---	81	81	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	1,700	1,700	---	---	---	---	---	---
Total	**35,000**	**3,500**	**39,000**	**35,000**	**3,500**	**39,000**	**60,000**	**6,000**	**66,000**

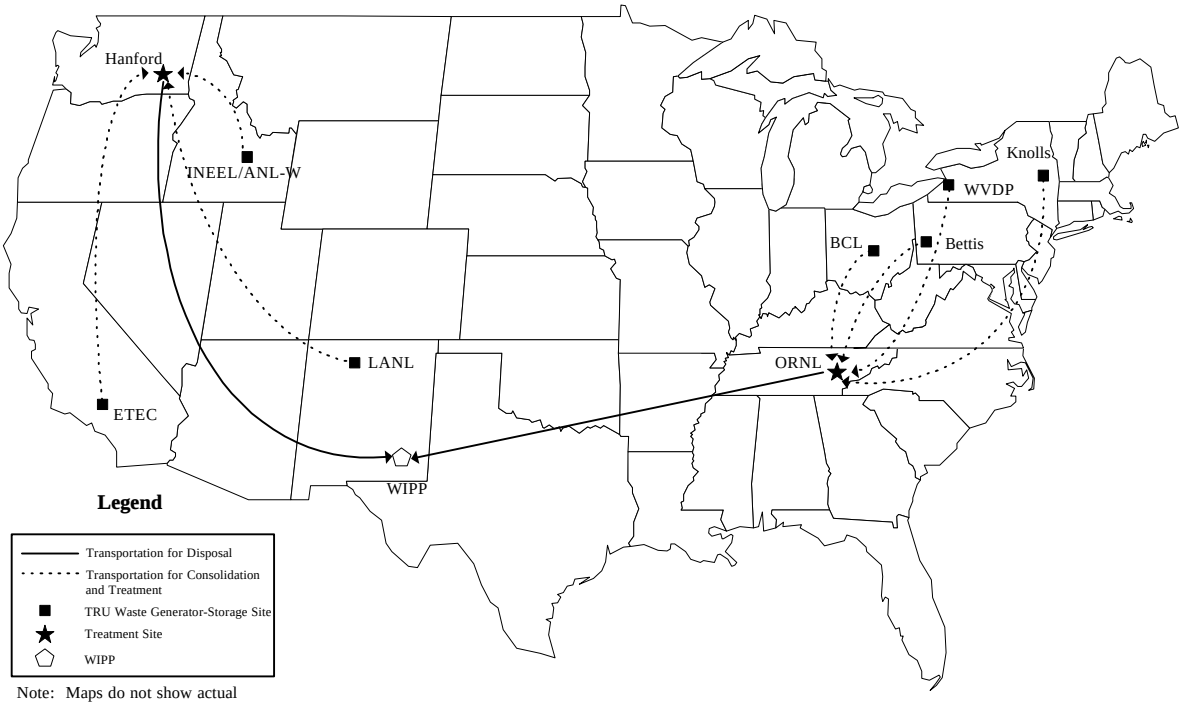
[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. have been rounded. Actual totals may differ due to rounding.
[b] Volumes include consolidation of waste as indicated on Figure 3-6.
[c] Post-treatment volumes have been adjusted to meet packaging and transportation criteria.
[d] Sites in boldface were included in SEIS-I.
[e] TRU waste commingled with PCBs is not included.
[f] Dashes indicate no waste.
[g] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

The timeline below presents the approximate schedule for disposal activities under Action Alternative 3. Sites would generate waste for 35 years, beginning in 1998. It would take 12 years to design and construct the treatment facilities for Action Alternative 3. The disposal of TRU waste would begin in 2010 and would continue for 190 years, ending in 2200. The disposal operations duration is based on the time needed to emplace the total volume of RH-TRU waste, assuming a maximum emplacement rate of 356 cubic meters (12,570 cubic feet) per year, a throughput rate of eight RH-72B canisters per week (DOE 1996b), and an operating time of 50 weeks per year. Decommissioning activities would last for up to 10 years and would be

CH-TRU Waste



RH-TRU Waste

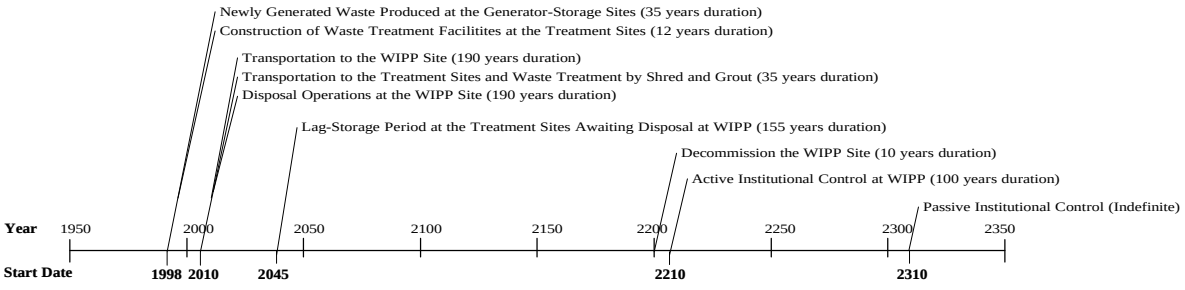


Note: Maps do not show actual transportation routes.

Figure 3-6
Movement of Waste for Action Alternative 3 [a]
(For complete names of facilities and waste volumes, see Tables 3-10 and 3-11)

[a] Although Pantex currently has no TRU waste, future decisions by the Department may result in TRU waste generation at Pantex.

followed by an active institutional control period assumed for analyses to last 100 years, ending in 2310. (Section 3.2.4.4 discusses methods that could be used to reduce operations time for this alternative.)



Timeline for the Implementation of Action Alternative 3

3.2.4.1 Activities at the Generator-Storage Sites

The activities at the generator-storage sites are the same as those described for the Proposed Action, with the exceptions that there would be approximately twice as much waste and that treatment sites would use a shred and grout process to treat the waste. It was assumed that all waste treatment facilities would be constructed over a period of 12 years and would be ready for operation in the year 2010. Waste treatment would occur over 35 years, through the year 2045, and lag storage of the TRU waste awaiting shipment would occur for 155 years, through the year 2200. Lag storage would be necessary due to the rate of emplacement of RH-TRU waste. The lag storage would be similar to that described in Section 3.2.2.1. Engineering details of the shred and grout process that would be used have not been finalized. Nevertheless, such a process would consist of shredding the TRU waste to fragments smaller than some limiting size, perhaps 15 centimeters (6 inches); combining the fragments with a cement-based grout; and placing the mixture in disposal drums. Additional information on the TRU waste treatment processes is presented in Chapter 2.

3.2.4.2 Transportation Activities

Transportation activities under this alternative would differ from those described for the Proposed Action in the following ways:

- More than twice as many shipments as needed for the Proposed Action (based on BIR-3) would be required to transport the Basic Inventory and Additional Inventory to WIPP due to a larger pretreatment waste volume and the volume increase resulting from treatment.

- The period of shipping to WIPP would occur for 190 years, through the year 2200.

- SEIS-II analyses for this alternative include three transportation scenarios. The first scenario uses only trucks, as described under the Proposed Action. The other two use a mix of maximum commercial rail and truck transportation or maximum dedicated rail and truck transportation, as described in Section 3.2.2.2. DOE would not build new rail lines. WIPP already has a rail spur leading to the facility.

3.2.4.3 Activities at WIPP

Under Action Alternative 3, excavation operations, TRU waste handling operations at the surface, CH-TRU waste emplacement operations, closure, and decommissioning would be the same as for the Proposed Action. This alternative would extend the operations time frame to as late as the year 2200 and would accept a larger total volume of TRU waste at WIPP. Seventy-one panels would be excavated to accommodate the additional waste, with 20 panels to accommodate CH-TRU and RH-TRU waste and 51 panels for RH-TRU waste only. Any expansion of WIPP capacity would require changes to the LWA, the C&C Agreement, and various permits to operate WIPP.

As in the Proposed Action, RH-TRU waste canisters would be emplaced in horizontal boreholes in the walls of the panels. Because of the increased volume of RH-TRU waste, other RH-TRU waste disposal options may be considered, including horizontal boreholes that could accommodate two canisters and vertical boreholes or trenches in the floors of disposal rooms.

Closure and institutional controls would be the same as those for the Proposed Action, except that decommissioning and assumed active institutional control period would extend through the year 2310 because of the additional years of operation. A berm would be constructed around the perimeter of the site. This berm would include 375 hectares (927 acres), 355 hectares (877 acres) of which would lie above the 71 panel equivalents, 12 hectares (30 acres) of which would be for the salt pile, and 8 hectares (20 acres) of which would be for surface facilities. DOE would restore the areas occupied by the salt pile and surface facilities, and, if necessary, any of the area overlying the disposal panels.

3.2.4.4 Reducing Operation Time

The 190 years of total operation time for treatment and emplacement of TRU waste under Action Alternative 3 is due to the large volume of RH-TRU waste to be emplaced, the increase in that volume due to treatment, and the assumptions that only one excavation shift will be used and that only 8 RH-TRU waste canisters will be emplaced per week. These assumptions were made to ensure all of the alternatives were comparable to the Proposed Action and to each other. During the public comment period, though, stakeholders stated that the operation time was too long and that DOE should consider methods of reducing it. Stakeholders also asked that the Final SEIS-II include greater detail on how the impacts would change if the operation time were reduced.

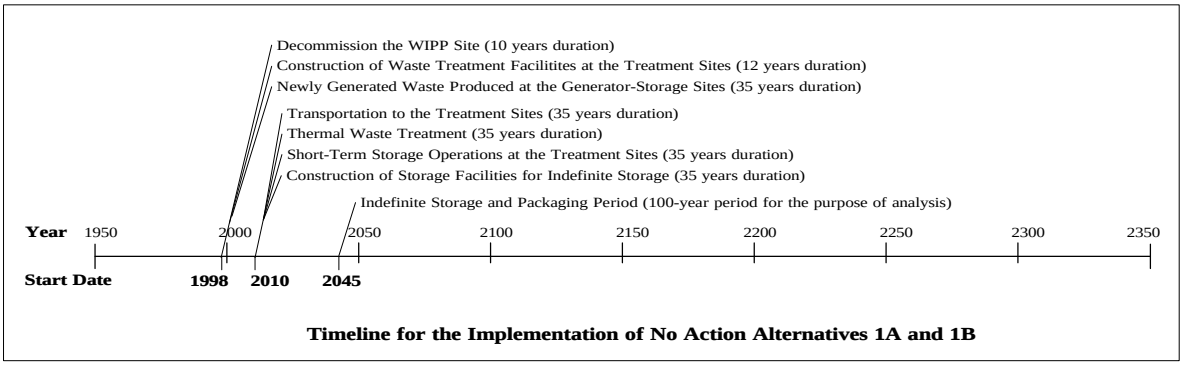
In response, this document includes analyses of impacts should the period of total operation be reduced from 162 years to 75 years by constructing new RH-TRU waste handling facilities and increasing the number of excavation crews. The 75 years would include 12 years to plan, design, and construct treatment facilities and 63 years for emplacement operations. The assumptions and description of operations presented for Action Alternative 3 above would apply, except for the following modifications:

- During the 12 years when treatment facilities would be planned, designed, and constructed, a new RH-TRU waste handling facility would be constructed at WIPP. The additional facility would include two RH-TRU waste handling areas and four new shafts into the facility. The four shafts would include a waste emplacement shaft, a salt removal shaft, an air intake shaft, and a ventilation shaft. Further NEPA review may need to be conducted, as appropriate, before any new facilities would be built.
- Two additional excavation crews would be used to excavate panels for the waste, increasing the excavation rate to three panels every two years. In all, an additional 90 WIPP employees would be hired.
- All transportation to WIPP would be completed in 63 years, following the 12-year period for construction of the treatment facilities.
- The capital cost of the new facility would be about $80 million; annual operating costs would increase by 10 percent.

3.2.5 No Action Alternative 1: Total Inventory (Including PCB-Commingled TRU Waste), Treat Thermally to Meet LDRs, Store Indefinitely, Dismantle WIPP

Under No Action Alternative 1, no waste would be shipped to WIPP. DOE would consolidate and thermally treat its inventory and would manage the treated waste indefinitely in newly engineered and constructed monitored storage facilities at the consolidation sites. A 65 percent reduction in volume was assumed due to the thermal treatment. The Department would dismantle the existing facilities at WIPP, salvage the equipment for other uses, and close the repository. Agreements and orders between DOE and various states, such as those under the Federal Facility Compliance Act, could require modification because of the extended time frame for storage.

Two waste treatment subalternatives were assumed for No Action Alternative 1. These two subalternatives are referred to as No Action Alternative 1A and 1B, respectively. Table 3-12 presents the CH-TRU waste volumes and Table 3-13 presents the RH-TRU waste volumes for No Action Alternative 1A. Figure 3-7 shows the flow of TRU waste between the sites. DOE would consolidate and treat CH-TRU waste at five sites (Hanford, INEEL, LANL, SRS, and RFETS) and RH-TRU waste at two sites (Hanford and ORNL). Table 3-14 presents the CH-TRU waste volumes and Table 3-15 presents the RH-TRU waste volumes for No Action Alternative 1B. Figure 3-8 shows the flow of TRU waste between sites. DOE would consolidate and treat CH-TRU waste at three sites (Hanford, INEEL, and SRS) and would treat RH-TRU waste at two sites (Hanford and ORNL). The timeline below presents the approximate schedule for No Action Alternatives 1A and 1B. Sites would generate waste for 35 years, beginning in 1998.



Timeline for the Implementation of No Action Alternatives 1A and 1B

Table 3-12
CH-TRU Waste Volumes for No Action Alternative 1A [a]

Site [d]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume [b] (cubic meters)			Post-Treatment Volume [c] (cubic meters)		
	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory
Hanford Site (Hanford)	57,000	63,000	120,000	59,000	63,000	122,000	21,000	22,000	43,000
Los Alamos National Laboratory (LANL)	21,000	14,000	35,000	21,000	14,000	35,000	7,400	4,900	12,000
Idaho National Engineering and Environmental Laboratory (INEEL) [f]	28,000	57,000	85,000	30,000	57,000	87,000	10,000	31,000	41,000
Argonne National Laboratory - West (ANL-W)	1,000	--- [g]	1,000	---	---	---	---	---	---
Argonne National Laboratory - East (ANL-E)	200	---	200	---	---	---	---	---	---
Savannah River Site (SRS)	12,000	4,900	17,000	14,000	5,200	20,000	5,000	1,800	6,800
Rocky Flats Environmental Technology Site (RFETS)	11,000	---	11,000	11,000	---	11,000	3,800	---	3,800
Oak Ridge National Laboratory (ORNL)	1,700	66	1,700	---	---	---	---	---	---
Lawrence Livermore National Laboratory (LLNL)	1,200	---	1,200	---	---	---	---	---	---
Nevada Test Site (NTS)	630	---	630	---	---	---	---	---	---
Mound Plant (Mound)	300	19	320	---	---	---	---	---	---
Bettis Atomic Power Laboratory (Bettis)	170	---	170	---	---	---	---	---	---
Sandia National Laboratories - Albuquerque (SNL)	17	1	18	---	---	---	---	---	---
Paducah Gaseous Diffusion Plant (PGDP)	8	---	8	---	---	---	---	---	---
U.S. Army Material Command (USAMC)	3	---	3	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	2	---	2	---	---	---	---	---	---
University of Missouri Research Reactor (U of Mo)	1	---	1	---	---	---	---	---	---
Ames Laboratory - Iowa State University (Ames)	1	---	1	---	---	---	---	---	---
ARCO Medical Products Company (ARCO)	---	1	1	---	---	---	---	---	---
Lawrence Berkeley Laboratory (LBL)	---	2	2	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	190	190	---	---	---	---	---	---
Total	**135,000**	**139,000**	**274,000**	**135,000**	**139,000**	**274,000**	**47,000**	**60,000**	**107,000**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Volumes include consolidation of waste as indicated on Figure 3-7.

[c] Post-treatment volumes have been adjusted to meet safe packaging criteria.

[d] Sites in boldface were included in SEIS-I.

[e] TRU waste commingled with PCBs is included.

[f] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

[g] Dashes indicate no waste.

It would take 12 years to design and construct the treatment facilities for No Action Alternatives 1A and 1B. The waste would be treated for 35 years and stored indefinitely. The treated TRU waste would be placed in and maintained at newly constructed storage facilities. WIPP would be decommissioned immediately. Decommissioning would last 10 years.

Table 3-13
RH-TRU Waste Volumes for No Action Alternative 1A [a]

Site [d]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume [b] (cubic meters)			Post-Treatment Volume [c] (cubic meters)		
	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory
Hanford Site (Hanford)	29,000	1,000	30,000	32,000	1,600	33,000	16,000	920	17,000
Los Alamos National Laboratory (LANL)	230	120	350	--- [f]	---	---	---	---	---
Idaho National Engineering and Environmental Laboratory (INEEL) [g]	220	440	660	---	---	---	---	---	---
Argonne National Laboratory - West (ANL-W)	1,700	---	1,700	---	---	---	---	---	---
Oak Ridge National Laboratory (ORNL)	3,100	120	3,200	3,700	1,900	5,600	1,800	960	2,800
Bettis Atomic Power Laboratory (Bettis)	9	---	9	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	7	---	7	---	---	---	---	---	---
Battelle Columbus Laboratories (BCL)	580	---	580	---	---	---	---	---	---
Knolls Atomic Power Laboratory (Knolls)	---	81	81	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	1,700	1,700	---	---	---	---	---	---
Total	**35,000**	**3,500**	**39,000**	**35,000**	**3,500**	**39,000**	**18,000**	**1,900**	**19,000**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Volumes include consolidation of waste as indicated on Figure 3-7.

[c] Post-treatment volumes have been adjusted to meet safe packaging criteria.

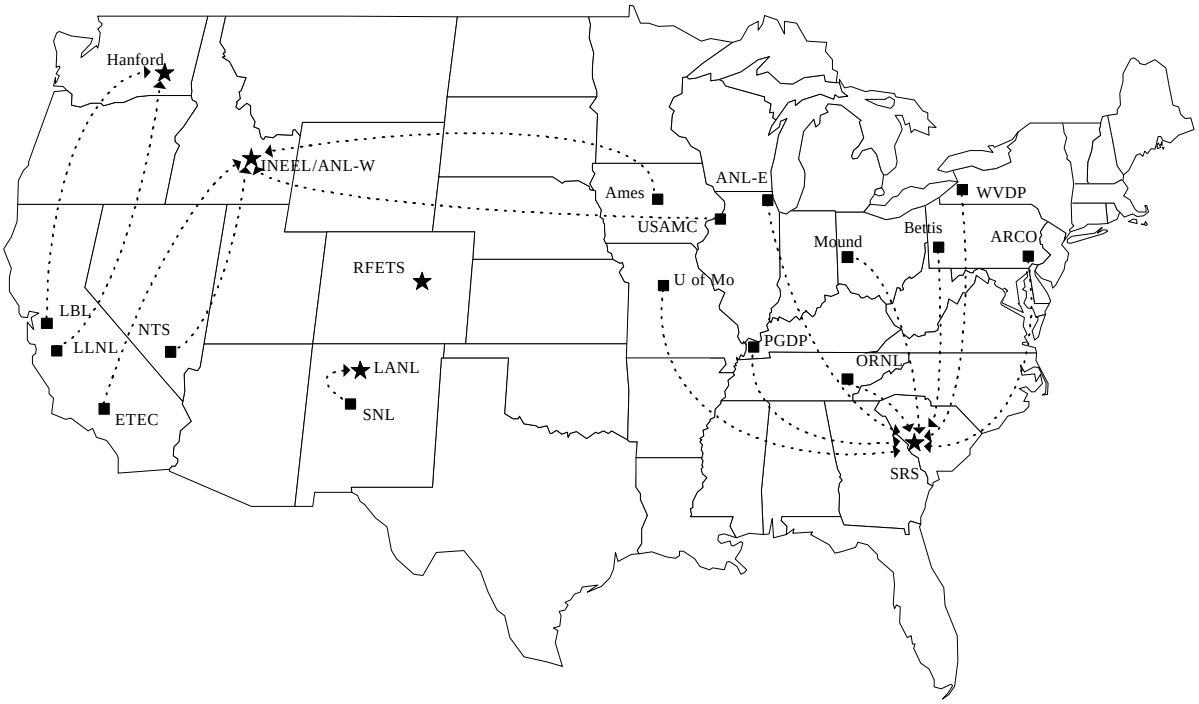
[d] Sites in boldface were included in SEIS-I.

[e] TRU waste commingled with PCBs is included.

[f] Dashes indicate no waste.

[g] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

CH-TRU Waste



RH-TRU Waste

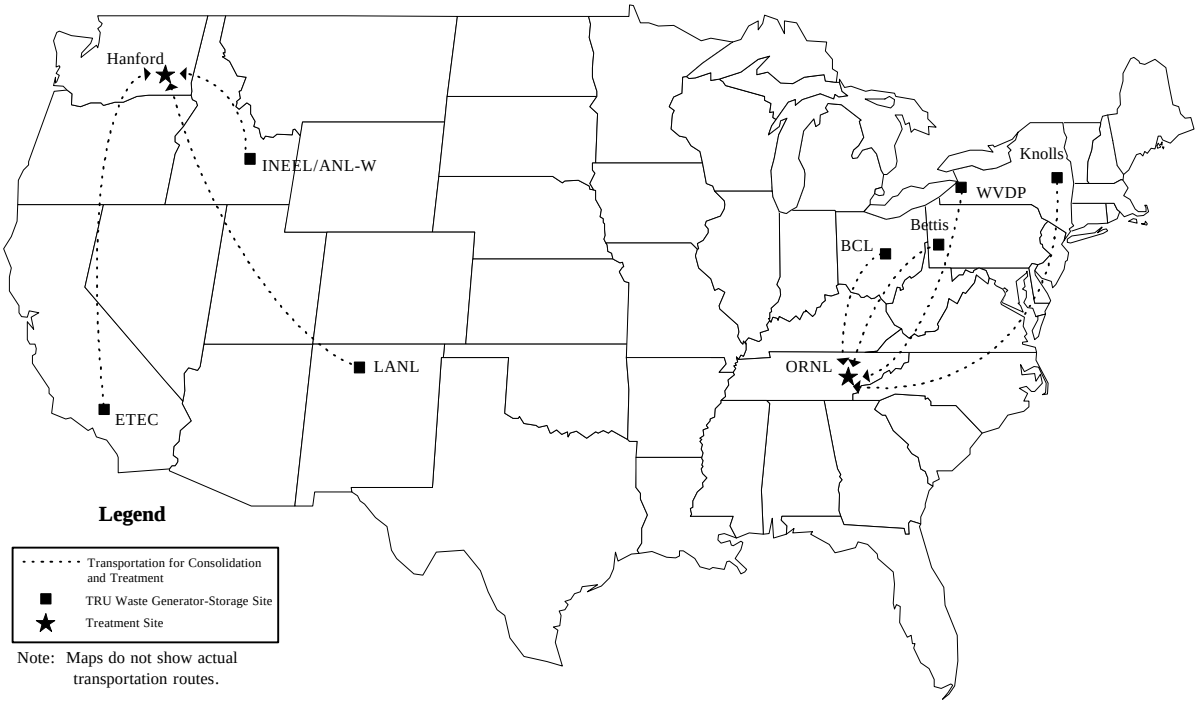


Figure 3-7
Movement of Waste for No Action Alternative 1A [a]
(For complete names of facilities and waste volumes, see Tables 3-12 and 3-13)

[a] Although Pantex currently has no TRU waste, future decisions by the Department may result in TRU waste generation at Pantex.

Table 3-14
CH-TRU Waste Volumes for No Action Alternative 1B [a]

Site [d]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume [b] (cubic meters)			Post-Treatment Volume [c] (cubic meters)		
	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory
Hanford Site (Hanford)	57,000	63,000	120,000	59,000	63,000	122,000	21,000	22,000	43,000
Los Alamos National Laboratory (LANL)	21,000	14,000	35,000	--- [f]	---	---	---	---	---
Idaho National Engineering and Environmental Laboratory (INEEL) [g]	28,000	57,000	85,000	62,000	71,000	133,000	22,000	36,000	57,000
Argonne National Laboratory - West (ANL-W)	1,000	---	1,000	---	---	---	---	---	---
Argonne National Laboratory - East (ANL-E)	200	---	200	---	---	---	---	---	---
Savannah River Site (SRS)	12,000	4,900	17,000	14,000	5,200	20,000	5,000	1,800	6,800
Rocky Flats Environmental Technology Site (RFETS)	11,000	---	11,000	---	---	---	---	---	---
Oak Ridge National Laboratory (ORNL)	1,700	66	1,700	---	---	---	---	---	---
Lawrence Livermore National Laboratory (LLNL)	1,200	---	1,200	---	---	---	---	---	---
Nevada Test Site (NTS)	630	---	630	---	---	---	---	---	---
Mound Plant (Mound)	300	19	320	---	---	---	---	---	---
Bettis Atomic Power Laboratory (Bettis)	170	---	170	---	---	---	---	---	---
Sandia National Laboratories - Albuquerque (SNL)	17	1	18	---	---	---	---	---	---
Paducah Gaseous Diffusion Plant (PGDP)	8	---	8	---	---	---	---	---	---
U.S. Army Materiel Command (USAMC)	3	---	3	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	2	---	2	---	---	---	---	---	---
University of Missouri Research Reactor (U of Mo)	1	---	1	---	---	---	---	---	---
Ames Laboratory - Iowa State University (Ames)	1	---	1	---	---	---	---	---	---
ARCO Medical Products Company (ARCO)	---	1	1	---	---	---	---	---	---
Lawrence Berkeley Laboratory (LBL)	---	2	2	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	190	190	---	---	---	---	---	---
Total	**135,000**	**139,000**	**274,000**	**135,000**	**139,000**	**274,000**	**47,000**	**60,000**	**107,000**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Volumes include consolidation of waste as indicated on Figure 3-8.

[c] Post-treatment volumes have been adjusted to meet safe packaging criteria.

[d] Sites in boldface were included in SEIS-I.

[e] TRU waste commingled with PCBs is included.

[f] Dashes indicate no waste.

[g] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

Table 3-15
RH-TRU Waste Volumes for No Action Alternative 1B [a]

Site [d]	Site Volume Through 2033 (cubic meters)			Pretreatment Consolidated Volume [b] (cubic meters)			Post-Treatment Volume [c] (cubic meters)		
	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory	Basic Inventory	Additional Inventory [e]	Total Inventory
Hanford Site (Hanford)	29,000	1,000	30,000	32,000	1,600	33,000	16,000	920	17,000
Los Alamos National Laboratory (LANL)	230	120	350	--- [f]	---	---	---	---	---
Idaho National Engineering and Environmental Laboratory (INEEL) [g]	220	440	660	---	---	---	---	---	---
Argonne National Laboratory - West (ANL-W)	1,700	---	1,700	---	---	---	---	---	---
Oak Ridge National Laboratory (ORNL)	3,100	120	3,200	3,700	1,900	5,600	1,800	960	2,800
Bettis Atomic Power Laboratory (Bettis)	9	---	9	---	---	---	---	---	---
Energy Technical Engineering Center (ETEC)	7	---	7	---	---	---	---	---	---
Battelle Columbus Laboratories (BCL)	580	---	580	---	---	---	---	---	---
Knolls Atomic Power Laboratory (Knolls)	---	81	81	---	---	---	---	---	---
West Valley Demonstration Project (WVDP)	---	1,700	1,700	---	---	---	---	---	---
Total	**35,000**	**3,500**	**39,000**	**35,000**	**3,600**	**39,000**	**18,000**	**1,900**	**19,000**

[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Volumes include consolidation of waste as indicated on Figure 3-8.

[c] Post-treatment volumes have been adjusted to meet safe packaging criteria.

[d] Sites in boldface were included in SEIS-I.

[e] TRU waste commingled with PCBs is included.

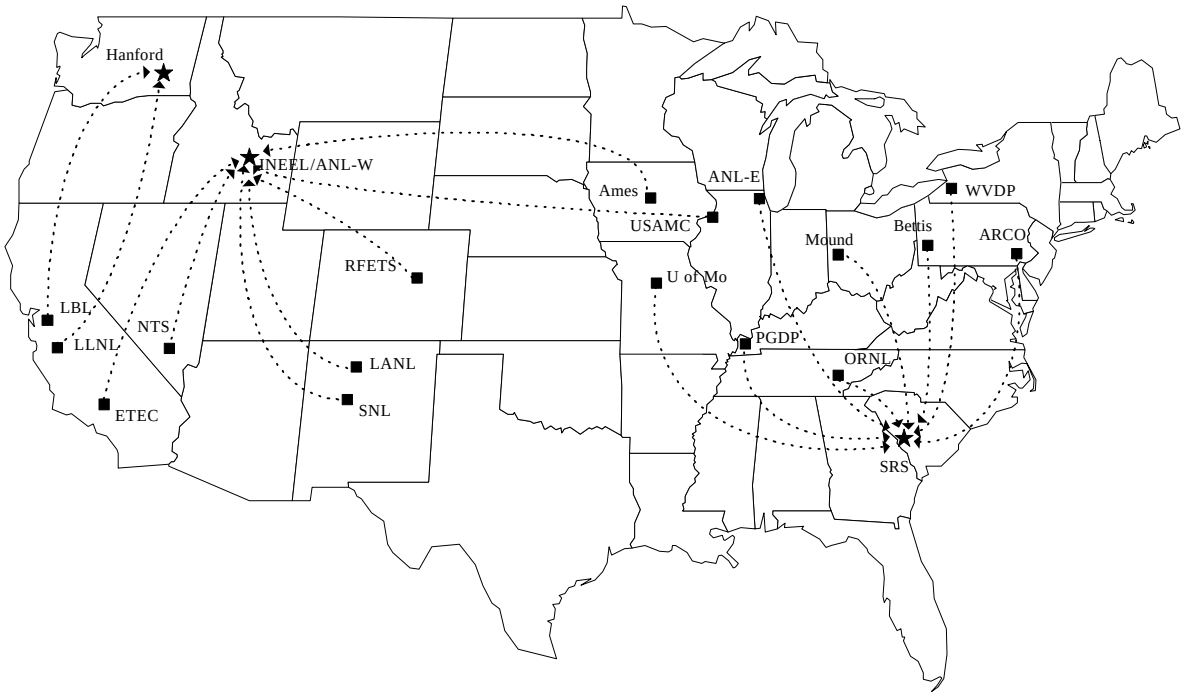
[f] Dashes indicate no waste.

[g] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

3.2.5.1 Activities at the Generator-Storage Sites

Consolidation sites would use a thermal treatment process that may involve vitrification. This process would destroy organic matter, thereby reducing the total volume of thermally treated waste. A vitrification process would add silica-based materials that would result in a glass-like product. The volumes shown in Tables 3-12 through 3-15 reflect the currently stored and projected volumes and any thermal treatment. Waste treatment facilities would be constructed over a period of 12 years and would be ready for operation in the year 2010. The treated waste would be managed for an indefinite period of time at the consolidation sites in newly engineered, monitored storage facilities. Though the Department would investigate designing packages with longer minimal shelf-lives than those currently used, to bound the impacts it was assumed for the SEIS-II analyses that CH-TRU waste packaging would be performed every 20 years. Currently used drums and waste boxes have a relatively short design life and would degrade over time due to corrosion. It was further assumed, for purposes of analysis, that the storage facilities themselves would be refurbished or replaced at least every 50 years, although the Department may attempt to design facilities with a longer lifetime under this alternative.

CH-TRU Waste



RH-TRU Waste

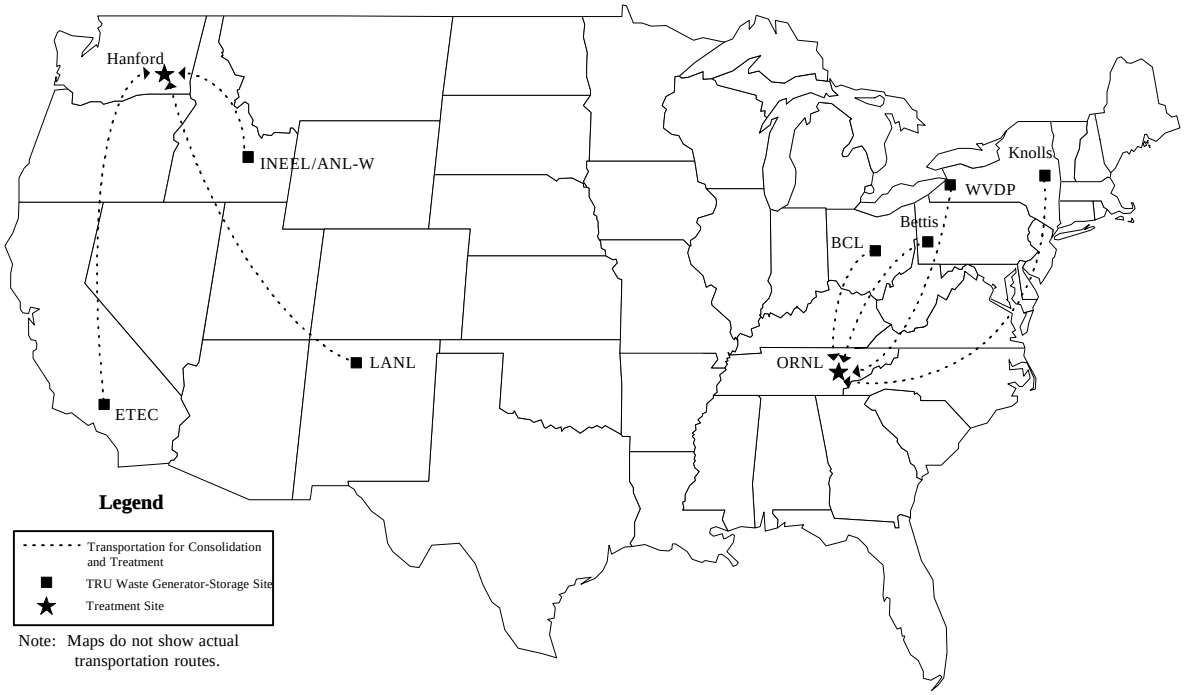


Figure 3-8
Movement of Waste for No Action Alternative 1B [a]
(For complete names of facilities and waste volumes, see Tables 3-14 and 3-15)

[a] Although Pantex currently has no TRU waste, future decisions by the Department may result in TRU waste generation at Pantex.

3.2.5.2 Transportation Activities

Transportation activities under this alternative would differ from those described for the Proposed Action in the following ways:

- No waste would be shipped to WIPP.
- The period of shipping to consolidation sites would begin in the year 2010.
- SEIS-II analyses for this alternative include three transportation scenarios. The first scenario uses only trucks, as described under the Proposed Action. The other two scenarios use a mix of maximum commercial rail and truck transportation and maximum dedicated rail and truck transportation, as described in Section 3.2.2.2.

3.2.5.3 Activities at WIPP

There would be no disposal activities at WIPP; the Department would terminate its WIPP mission. DOE would fill the shafts with salt from the storage pile and then seal the excavation. The aboveground site would be restored and perhaps returned to the U.S. Bureau of Land Management (BLM). DOE would salvage all usable equipment and dismantle and remove the surface facilities.

3.2.6 No Action Alternative 2: Basic Inventory, Treat Newly Generated TRU Waste to WAC, Store at Generator Sites, Dismantle WIPP

Activities associated with No Action Alternative 2 are discussed below. There would be no treatment of stored waste, although newly generated waste would be treated to the requirements of WAC for safe storage. There would be no transportation of any of the waste from the generator-storage sites, unless future agreements require such movement.

3.2.6.1 Activities at the Generator-Storage Sites

Under No Action Alternative 2, no waste would be shipped to WIPP. Current TRU waste management practices would continue at all sites, except where DOE has entered into agreements to have waste removed from small quantity sites to facilitate safe long-term storage. In such cases, shipment of TRU waste from a small quantity site to a consolidation site would be by truck. Newly generated TRU waste would be treated to WAC for safe storage. Existing TRU waste in storage would not be treated but would continue to be managed under current practices. Newly generated waste would constitute about 73,000 cubic meters (2,600,000 cubic feet) of the 135,000 cubic meters (4,800,000 cubic feet) of CH-TRU waste and 32,000 cubic meters (1,100,000 cubic feet) of the 35,000 cubic meters (1,200,000 cubic feet) of RH-TRU waste in the Basic Inventory. Table 3-16 presents TRU waste volumes for No Action Alternative 2.

Table 3-16
TRU Waste Volumes for No Action Alternative 2 [a]

Site [b]	Site Volume Through 2033 (cubic meters)		Stored Volume (1995) (cubic meters)		Newly Generated Post-Treatment Volume (cubic meters)	
	CH-TRU	RH-TRU	CH-TRU	RH-TRU	CH-TRU	RH-TRU
Hanford Site (Hanford)	57,000	29,000	12,000	200	45,000	29,000
Los Alamos National Laboratory (LANL)	21,000	230	11,000	90	10,000	130
Idaho National Engineering and Environmental Laboratory (INEEL) [c]	28,000	220	28,000	220	---	---
Argonne National Laboratory - West (ANL-W)	1,000	1,700	7	20	1,000	1,700
Argonne National Laboratory - East (ANL-E)	200	--- [d]	25	---	180	---
Savannah River Site (SRS)	12,000	---	2,900	---	9,200	---
Rocky Flats Environmental Technology Site (RFETS)	11,000	---	4,900	---	6,000	---
Oak Ridge National Laboratory (ORNL)	1,700	3,100	1,300	2,500	350	600
Lawrence Livermore National Laboratory (LLNL)	1,200	---	230	---	960	---
Nevada Test Site (NTS)	630	---	620	---	10	---
Mound Plant (Mound)	300	---	300	---	---	---
Bettis Atomic Power Laboratory (Bettis)	170	9	---	---	170	9
Sandia National Laboratories - Albuquerque (SNL)	17	---	7	---	10	---
Paducah Gaseous Diffusion Plant (PGDP)	8	---	---	---	8	---
U.S. Army Materiel Command (USAMC)	3	---	3	---	---	---
Energy Technology Engineering Center (ETEC)	2	7	2	6	---	1
University of Missouri Research Reactor (U of Mo)	1	---	1	---	1	---
Ames Laboratory - Iowa State University (Ames)	1	---	1	---	1	---
Battelle Columbus Laboratories (BCL)	---	580	---	580	---	---
Total	**135,000**	**35,000**	**62,000**	**3,600**	**73,000**	**32,000**

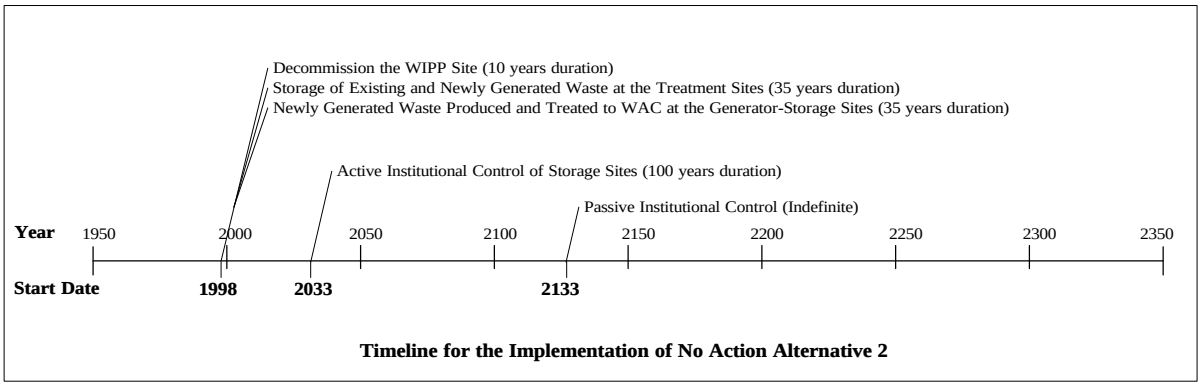
[a] The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites. Waste exceeding 50 ppm of PCBs cannot be disposed of in WIPP unless treated to remove the PCBs first. Site volumes through 2033 are the sum of similar columns on Tables 2-2 and 2-3. Volumes have been rounded. Actual totals may differ due to rounding.

[b] Sites in boldface were included in SEIS-I.

[c] INEEL and ANL-W are considered as one site in the WM PEIS and, therefore, counted as one site in SEIS-II.

[d] Dashes indicate no waste.

A timeline below presents the approximate schedule under No Action Alternative 2. Sites would continue to generate waste for 35 years and would store the waste. WIPP would be decommissioned beginning immediately.



Timeline for the Implementation of No Action Alternative 2

3.2.6.2 Transportation Activities

The generator-storage sites would only ship waste to the consolidation sites if it were to facilitate safe storage or requirements of future agreements. No waste would be shipped to WIPP.

3.2.6.3 Activities at WIPP

There would be no disposal activities at WIPP; the Department would terminate its WIPP mission. DOE would fill the shafts with salt and then seal the excavation. DOE would restore the aboveground site and perhaps return it to the BLM. DOE would salvage all usable equipment and dismantle and remove the surface facilities according to the WIPP Land Management Plan (DOE 1993).

3.3 ALTERNATIVES CONSIDERED BUT NOT ANALYZED IN DETAIL

SEIS-II does not include detailed analyses of several alternatives discussed during the scoping process. These alternatives were not analyzed in detail because — depending on the alternative — they are not technically viable, would not adequately or economically meet DOE's need to safely dispose of TRU waste in a timely manner, involve additional environmental and policy concerns that would need to be accommodated, or are otherwise unreasonable in the present context. The following alternatives are not analyzed in detail.

Transmutation. An accelerator or a reactor could possibly be used to transmute long-lived radionuclides into short-lived or stable nuclides; however, the transmutation process has not been demonstrated for TRU waste. Also, transmutation is a technology that has not yet been proven for production-size facilities. The transmutation process, as well as reactor operations, would result in fission products that would have to be disposed of as radioactive waste by some other method. This alternative was considered and rejected for the same reasons in the 1980 *Final Environmental Impact Statement for the Waste Isolation Pilot Plant* (FEIS) (DOE 1980). DOE is not aware of any proven physical or chemical techniques that will neutralize or change the fundamental physical process of radioactive decay. The National Academy of Sciences (NAS) (1996) published a report that evaluated the relative effects, costs, and feasibility of employing separations and transmutation technologies in DOE programs. (These technologies would be used for managing spent nuclear fuel for civilian power reactors and radioactive wastes in tanks at selected existing defense production reactor sites. To DOE's knowledge there has been no similar detailed, independent study with respect to TRU waste.) Based on this research, DOE does not believe that transmutation represents a technically achievable, cost-effective, near-term alternative for the elimination or disposal of TRU waste.

Coprocess with high level waste and vitrify[1]. TRU and high level waste could be combined and mixed with molten glass. This vitrification would produce highly radioactive glass "logs" that would have to be stored in interim storage and eventually buried in a geologic repository (NAS 1994). While the *Storage and Disposition of Weapons-Usable Fissile Materials Programmatic Environmental Impact Statement* (DOE 1996c) considered this process to be a reasonable alternative for analysis, it is a much less reasonable alternative for TRU waste. The technical difficulties of thermal loading in a high-level waste repository, the operational difficulties

[1] Vitrification of TRU waste not mixed with high-level waste is considered in SEIS-II.

SEIS-II AND THE WM PEIS ALTERNATIVES

Each SEIS-II alternative reflects an alternative in the WM PEIS in the way consolidation of waste is assumed.

The SEIS-II Proposed Action assumes, for the purposes of analyses, consolidation similar to the WM PEIS Decentralized Alternative, which was the basis for the WM PEIS preferred alternative. As in the WM PEIS Decentralized Alternative, the Proposed Action assumes that TRU waste would be treated to WAC at the facility where it currently is stored or would be generated. The waste would then be consolidated at the 10 facilities with the largest volume of waste to await disposal at WIPP. Those 10 sites are Hanford, LANL, INEEL, ANL-East, SRS, RFETS, ORNL, Lawrence Livermore National Laboratory (LLNL), NTS, and the Mound Plant (Mound). The SEIS-II inventory includes small quantities of TRU waste from several sites that were not considered for the WM PEIS. Waste from these sites would be consolidated at the closest site with larger volumes, if necessary.

The SEIS-II Action Alternative 1 also assumes, for analysis purposes, consolidation similar to the WM PEIS Decentralized Alternative. TRU waste would be treated to WAC at the facility where it currently is stored or would be generated. The waste would then be consolidated at the same 10 facilities as assumed for the Proposed Action. (The major difference between the SEIS-II Proposed Action and the SEIS-II Action Alternative 1 is the amount of waste to be disposed of.)

The three SEIS-II Action Alternative 2 subalternatives assume, for analysis purposes, consolidation similar to the WM PEIS Regionalized 2, Regionalized 3, and Centralized Alternatives. In each, the TRU waste would be consolidated at treatment sites where it would be treated by a thermal process to meet the RCRA LDRs. The three different consolidation options considered under Action Alternative 2 are:

- **Action Alternative 2A:** Assumes for analysis that CH-TRU waste would be treated at Hanford, SRS, RFETS, LANL, and INEEL/ANL-W. Assumes that RH-TRU waste would be treated at Hanford and ORNL. The consolidation used for analysis is similar to the WM PEIS Regionalized 2 Alternative.
- **Action Alternative 2B:** Assumes for analysis that CH-TRU waste would be treated at Hanford, SRS, and INEEL/ANL-W. Assumes that RH-TRU waste would be treated at Hanford and ORNL. The consolidation used for analysis is similar to the WM PEIS Regionalized 3 Alternative.
- **Action Alternative 2C:** Assumes for analysis that CH-TRU waste would be treated at WIPP. Assumes that RH-TRU waste would be treated at Hanford and ORNL. The consolidation used for analysis is similar to the WM PEIS Centralized Alternative.

The SEIS-II Action Alternative 3 is similar to the WM PEIS Regionalized 1 Alternative. For both alternatives, TRU waste would be consolidated at regional sites throughout the country and treated by a shred and grout process before shipping the TRU waste to WIPP. CH-TRU waste would be treated at Hanford, LANL, RFETS, SRS, and INEEL/ANL-W. RH-TRU waste would be treated at Hanford and ORNL.

The two SEIS-II No Action Alternative 1 subalternatives are similar to the WM PEIS Regionalized 2 and Regionalized 3 Alternatives. The waste would be treated at the same sites described above for the SEIS-II Action Alternatives 2A, 2B, and 2C. SEIS-II No Action Alternative 1A is similar to the WM PEIS Regionalized 2 Alternative; SEIS-II No Action Alternative 1B is similar to the WM PEIS Regionalized 3 Alternative.

The SEIS-II No Action Alternative 2 is similar to both the WM PEIS Decentralized and No Action Alternatives. The currently stored waste would be left untreated. Newly generated waste would be treated to WAC. All waste would be stored at the sites where it is currently stored or would be generated.

that a large additional volume of TRU waste would cause, and potential legislative clarification or Nuclear Regulatory Commission certification by rule, make this alternative unreasonable.

Disposal in space. This alternative was considered and rejected in the FEIS. The disposal of TRU waste in a low earth orbit would not be sufficient because material in such an orbit would fall back to earth over a time span that is short as compared to the necessary disposal time and decay time of the TRU waste. Therefore, the waste would have to be launched into an orbit around the sun that is unlikely to encounter the earth or be put on a path to fall into the sun or escape the solar system entirely. The type and number of rockets needed for this type of launch would be very expensive, and the rockets would have to be very reliable. Research shows that even with reliable rockets the possibility of a rocket failure exists, and such a failure could result in the waste reentering from space (NAS 1994).

Underground detonation. Such detonations would produce a large amount of hazardous fission products. Research shows that the waste form resulting from a detonation would be somewhat unpredictable and it would be embedded in an underground location not selected for, or designed as, a long-term repository (NAS 1994). Because of the volume of waste to be disposed of, a large number of detonations would be required. Also, the geologic environment around the detonation points would be greatly disturbed. The manufacture of the explosive devices used in the detonations would generate more waste. This alternative would present additional environmental and policy concerns that would have to be addressed.

Subseabed disposal. This alternative was considered and rejected in the FEIS. Subseabed disposal of TRU waste would involve implanting canisters of TRU waste tens of meters into deep ocean sediments by free-fall penetration or other techniques (DOE 1980). In addition, subseabed disposal is prohibited by international treaties, and further development would be required. The U.S. program studying subseabed disposal was canceled in 1986, and no other country is currently pursuing such research.

Deep borehole disposal. This alternative involves drilling or sinking very deep boreholes or shafts (3,000-meters [9,840-feet] or more) and placing TRU waste canisters into these holes. This method relies on the surrounding rock to contain the waste and on the great depths to delay the release and reentry of radioactive material into the biosphere. This disposal method was reviewed in the FEIS (DOE 1980) and was ruled out because of substantial technical challenges in characterizing the geological conditions at the depth of interest, severe engineering problems in excavating deep holes and emplacing waste canisters, and the large number of boreholes (800 to 1,300) estimated to be required. Deep borehole disposal was evaluated as a candidate technology for possible disposal of surplus fissile materials (DOE 1996c). However, the technology may be more practicable for disposal of surplus fissile materials than for disposal of TRU waste because the volume of fissile materials potentially requiring disposal is many times smaller than the volume of TRU waste. Also, because many years of investigation and development would be needed before this method might be available for the disposal of TRU waste, selection of this technology would considerably delay the disposal of TRU waste.

Greater confinement (shallow borehole). This disposal method involves burial of waste in containers engineered to provide multiple barriers in shallow boreholes at a depth of about 100 feet. At many DOE sites, waste buried at this depth would likely interact with groundwater and could eventually pose an environmental and human health hazard. Greater confinement

disposal is being used for some waste types at the NTS, which has a deep water table, and greater confinement disposal of small quantities of TRU waste in this manner might be feasible. The degree of isolation that could be provided by greater confinement disposal over the 10,000-year-plus period WIPP would be expected to isolate waste is unknown, but this relatively shallow burial method offers no apparent advantage over disposal at WIPP. The need to evaluate the ability of any anticipated greater confinement disposal site to isolate waste would further delay disposal of TRU waste by several years. For the volume of waste that DOE proposes to dispose of in WIPP, greater confinement disposal would be a less cost-effective method of disposal.

Geologic repositories at sites other than WIPP. Three general classes of geologic media have been considered in the past for the disposal of radioactive waste (DOE 1980). These geologic media are salt, igneous rocks (granite, basalt, and tuff), and argillaceous rocks (shale). Salt is a favorable disposal media because of its thermal and physical properties and because its very survival for hundreds of millions of years has demonstrated its isolation from circulating groundwater and the stability of the geologic formations in which it is located (DOE 1980).

Alternative Engineered Barriers. Regulations within 40 CFR Part 194 suggest that alternative engineered barriers, including some not specifically examined here (e.g., supercompaction, improved waste canisters, grout and bentonite backfill) should be considered. The Department examined these as alternatives and determined based on the evaluation conducted in the *Engineered Alternatives Cost/Benefit Study Final Report* (DOE 1995b) that they were less effective than the engineered barriers examined in SEIS-II.

Other Suggestions. Zircon technology and changing the state of atoms to "supercold" in order to slow down radionuclide activity were technologies suggested for TRU waste treatment methods during the public scoping process. None of these technologies are currently technically or economically feasible, and their use as treatment or disposal alternatives would require additional research.

3.4 COMPARISON OF THE PROPOSED ACTION AND ALTERNATIVES

Table 3-17 gives a tabular comparison of the major features of the Proposed Action and the alternatives. This table is meant to help the reader understand the differences and similarities among the different courses of action described in SEIS-II. Figures 3-9 and 3-10 provide graphical comparisons of the CH-TRU and RH-TRU post-treatment waste volumes that would be disposed of according to alternative.

Over the life of the campaign, routine operation under the Proposed Action could result in five estimated worker fatalities at waste treatment sites and three worker fatalities at WIPP. Truck transportation under the Proposed Action could result in an estimated additional eight deaths among members of the public and crew. Although highly unlikely, the most severe accident, a severe truck accident with a maximum radionuclide inventory having a frequency of less than 7.5×10^{-7} per accident, could result in an additional 16 deaths. The waste disposed of at WIPP under the Proposed Action would be isolated from the environment for more than 10,000 years unless an intrusion by drilling occurred. If an intrusion occurred, radionuclides could reach the Culebra Dolomite, but impacts would be negligible. Health impacts due to any released waste at the storage sites could vary depending on the population density in the vicinity at the time the waste was released. The Proposed Action would be the least expensive of the action alternatives ($19.03 billion in 1994 dollars, $10.13 billion when the costs are discounted).

Table 3-17
Summary of WIPP SEIS-II Alternatives

Comparison Parameters	*Proposed Action (Preferred Alternative):* Basic Inventory, Treat to WAC, Dispose of at WIPP	*Action Alternative 1:* Total Inventory (Except PCB-Commingled TRU Waste), Treat to WAC, Dispose of at WIPP	*Action Alternative 2:* Total Inventory (Including PCB-Commingled TRU Waste), Treat Thermally to Meet LDRs, Dispose of at WIPP	*Action Alternative 3:* Total Inventory (Except PCB-Commingled TRU Waste), Treat by Shred and Grout, Dispose of at WIPP	*No Action Alternative 1:* Total Inventory (Including PCB-Commingled TRU Waste), Treat Thermally to Meet LDRs, Store Indefinitely, Dismantle WIPP	*No Action Alternative 2:* Basic Inventory, Treat Newly Generated TRU Waste to WAC, Store at Generator Sites, Dismantle WIPP [a]
Waste Type	Defense-related, post-1970 TRU waste in retrievable storage and newly generated through the year 2033 (Basic Inventory).	Basic Inventory plus other DOE-owned or controlled waste including non-defense, commercial, previously disposed of waste, and excluding PCB-commingled waste (Additional Inventory).	Basic Inventory plus Additional Inventory (including PCB-commingled waste).	Basic Inventory plus Additional Inventory (excluding PCB-commingled waste).	Basic Inventory plus Additional Inventory (including PCB-commingled waste).	Same as Proposed Action.
Post-Treatment Volume[b] to be Disposed of at WIPP, or Stored	CH-TRU: 168,500 m^3 (5,950,000 ft^3) RH-TRU: 7,080 m^3 (250,000 ft^3) Excess Waste[c] RH-TRU 43,000 m^3 (1,500,000 ft^3)	CH-TRU: 281,000 m^3 (9,900,000 ft^3) RH-TRU: 55,000 m^3 (2,000,000 ft^3)	CH-TRU: 107,000 m^3 (3,800,000 ft^3) RH-TRU: 19,000 m^3 (690,000 ft^3)	CH-TRU: 334,000 m^3 (11,800,000 ft^3) RH-TRU: 66,000 m^3 (2,300,000 ft^3)	CH-TRU: 107,000 m^3 (3,800,000 ft^3) RH-TRU: 19,000 m^3 (690,000 ft^3)	CH-TRU: 135,000 m^3 (4,800,000 ft^3) RH-TRU: 35,000 m^3 (1,200,000 ft^3)
Waste Consolidation Locations (assumed for purposes of analyses; actual consolidation would be in accordance with the ROD for the WM PEIS)	18 sites total - WAC treatment of CH-TRU at the largest sites and store at 10 largest sites[d]. Ship to WIPP. - WAC treatment of RH-TRU at Hanford, INEEL/ANL-W, ORNL, and LANL. Ship to WIPP.	22 sites total - Same as Proposed Action except two other sites (LBL, WVDP) consolidate and treat CH-TRU at Mound and Hanford.	22 sites total Action Alternative 2A - LDR treatment of CH-TRU at Hanford, INEEL, LANL, SRS, and RFETS. - LDR treatment of RH-TRU at Hanford and ORNL. Action Alternative 2B - LDR treatment of CH-TRU at Hanford, INEEL, and SRS. - LDR treatment of RH-TRU at Hanford and ORNL. Action Alternative 2C - LDR treatment of CH-TRU at WIPP. - LDR treatment of RH-TRU at Hanford and ORNL.	22 sites total - Shred and grout treatment of CH-TRU at Hanford, INEEL, LANL, SRS, and RFETS. - Shred and grout RH-TRU at Hanford and ORNL.	22 sites total No Action Alternative 1A - LDR treatment of CH-TRU at Hanford, INEEL, LANL, SRS, and RFETS. - LDR treatment of RH-TRU at Hanford and ORNL. No Action Alternative 1B - LDR treatment of CH-TRU at Hanford, INEEL, and SRS. - LDR treatment of RH-TRU at Hanford and ORNL.	Minimal consolidation to ensure safe storage; however, no sites would ship to WIPP.
Waste Treatment	Treat to meet WAC.	Treat to meet WAC.	Thermal treatment to meet the LDRs (including PCB-commingled waste).	Treatment by shred and grout.	Thermal treatment to meet the LDRs (including PCB-commingled waste). Package every 20 years indefinitely.	Newly generated waste treated to WAC.

Table 3-17
Summary of WIPP SEIS-II Alternatives — Continued

Comparison Parameters	*Proposed Action (Preferred Alternative):* Basic Inventory, Treat to WAC, Dispose of at WIPP	*Action Alternative 1:* Total Inventory (Except PCB-Commingled TRU Waste), Treat to WAC, Dispose of at WIPP	*Action Alternative 2:* Total Inventory (Including PCB-Commingled TRU Waste), Treat Thermally to Meet LDRs, Dispose of at WIPP	*Action Alternative 3:* Total Inventory (Except PCB-Commingled TRU Waste), Treat by Shred and Grout, Dispose of at WIPP	*No Action Alternative 1:* Total Inventory (Including PCB-Commingled TRU Waste), Treat Thermally to Meet LDRs, Store Indefinitely, Dismantle WIPP	*No Action Alternative 2:* Basic Inventory, Treat Newly Generated TRU Waste to WAC, Store at Generator Sites, Dismantle WIPP [a]
Transportation Mode	Truck. The Preferred Alternative reserves the option of rail transportation.	Three options: - Truck only - Maximum[e] commercial rail - Maximum dedicated rail	Three options: - Truck only - Maximum[e] commercial rail - Maximum dedicated rail	Three options: - Truck only - Maximum[e] commercial rail - Maximum dedicated rail	Three options: - Truck only - Maximum[e] commercial rail - Maximum dedicated rail	Truck only.
Disposal Operations	CH-TRU stacked in disposal rooms. RH-TRU placed in horizontal boreholes. RH-TRU disposal would start 6 years after CH-TRU and 7,080 m^3 (250,000 ft^3) of RH-TRU can be disposed of. 10 panel equivalents required at WIPP.[f]	CH-TRU stacked in disposal rooms. RH-TRU would be placed in either of horizontal and vertical boreholes, and/or provided extra shielding to CH-TRU levels. 68 panel equivalents required at WIPP.	CH-TRU stacked in disposal rooms. RH-TRU would be placed in either of horizontal and vertical boreholes, and/or provided extra shielding to CH-TRU levels. 75 panel equivalents required at WIPP.	CH-TRU stacked in disposal rooms. RH-TRU would be placed in either of horizontal and vertical boreholes, and/or provided extra shielding to CH-TRU levels. 71 panel equivalents required at WIPP.	No disposal. CH-TRU and RH-TRU would be in newly engineered, monitored storage at treatment sites.	No disposal. CH-TRU and RH-TRU continue to use existing storage.
WIPP Operations Time Frame [g]	Receive and emplace waste beginning 1998 for 35 years. Decommissioning for 10 years and active institutional control for 100 years, ending in 2143.	Same as Proposed Action, lag storage for 125 years and disposal would be for 160 years, until 2158; active institutional control ending in 2268.	Waste disposal and thermal treatment to meet the LDRs would begin in 2010 after treatment facility construction. Lag storage for 115 years. Disposal would be for 150 years, until 2160. Decommissioning and active institutional control would be the same as the Proposed Action, ending in 2270.	Waste disposal and shred and grout treatment would begin in 2010 after treatment facility construction Lag storage for 155 years. Disposal would be for 190 years, until 2200. Decommissioning and active institutional control would be the same as the Proposed Action, ending in 2310.	Dismantle and close WIPP in 10 years. Thermal treatment to meet the LDRs would begin in 2010 after treatment facility construction. Package and manage indefinitely at treatment sites.	Dismantle and close WIPP. Sites generate waste for 35 years beginning in 1998. Storage at the generator-storage sites evaluated for 35 years, ending in 2033. Active institutional control at generator-storage sites until 2133.
WIPP Institutional Control Site Area	70 hectares (175 acres)	360 hectares (890 acres)	395 hectares (976 acres)	375 hectares (927 acres)	20 hectares (50 acres) (Only for 10 years during decommissioning)	20 hectares (50 acres) (Only for 10 years during decommissioning)

[a] New facilities may be constructed in the future pursuant to future NEPA review.

[b] These values correspond to the Post-Treatment Consolidated Volume and Post-Treatment Disposal Volume data in Tables 3-1 through 3-16; differences in the numbers are due to rounding. The inventory for SEIS-II is based on BIR-3, which takes into account potential thermal treatment at some sites.

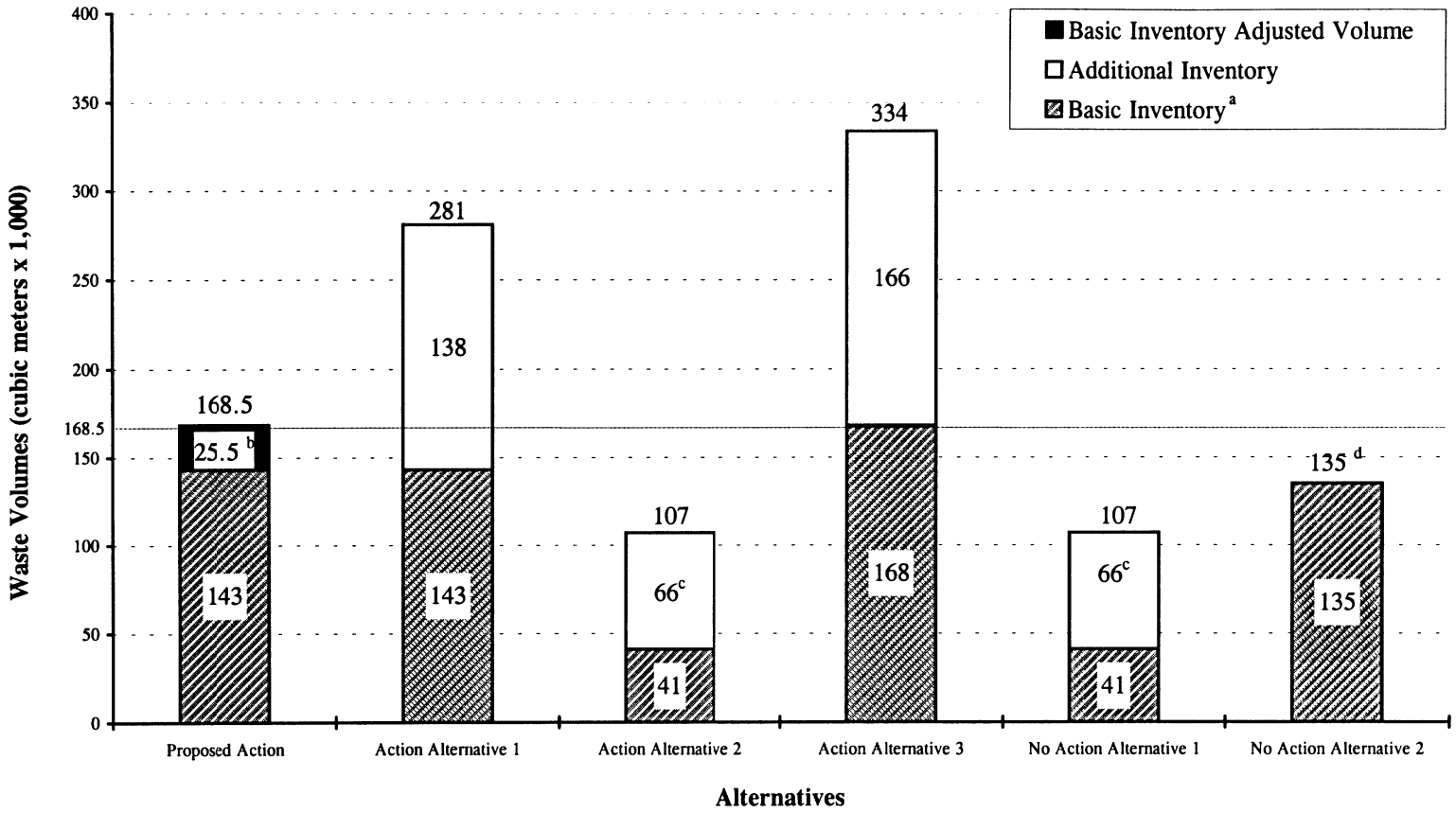
[c] Recent estimates in the *National Transuranic Waste Management Plan* indicate there would be no excess RH-TRU waste; see Appendix J.

[d] The 10 largest generator-storage sites are ANL-E, Hanford, INEEL/ANL-W, LANL, LLNL, Mound, NTS, ORNL, RFETS, and SRS.

[e] Maximum rail is used to denote that 18 of the 22 sites have rail facilities nearby; the remaining sites would ship by truck. Areas and volumes have been rounded.

[f] Under the Proposed Action, the consequence analysis for RH-TRU waste is based on 7,080 cubic meters (250,000 cubic feet), the maximum disposal volume of RH-TRU waste that is allowable at WIPP under the Consultation and Cooperation Agreement. The disposal strategy is to emplace RH-TRU waste canisters in the panel room walls prior to stacking CH-TRU waste in the rooms. At startup, however, a lag in RH-TRU waste availability is anticipated that would result in only CH-TRU waste initially being disposed of. The actual amount of RH-TRU waste disposed of, therefore, may be as low as 4,300 cubic meters.

[g] These time frames are those presented in the Draft SEIS-II. For reduced time frames, see Sections 3.2.2.4, 3.2.3.4, and 3.2.4.4.



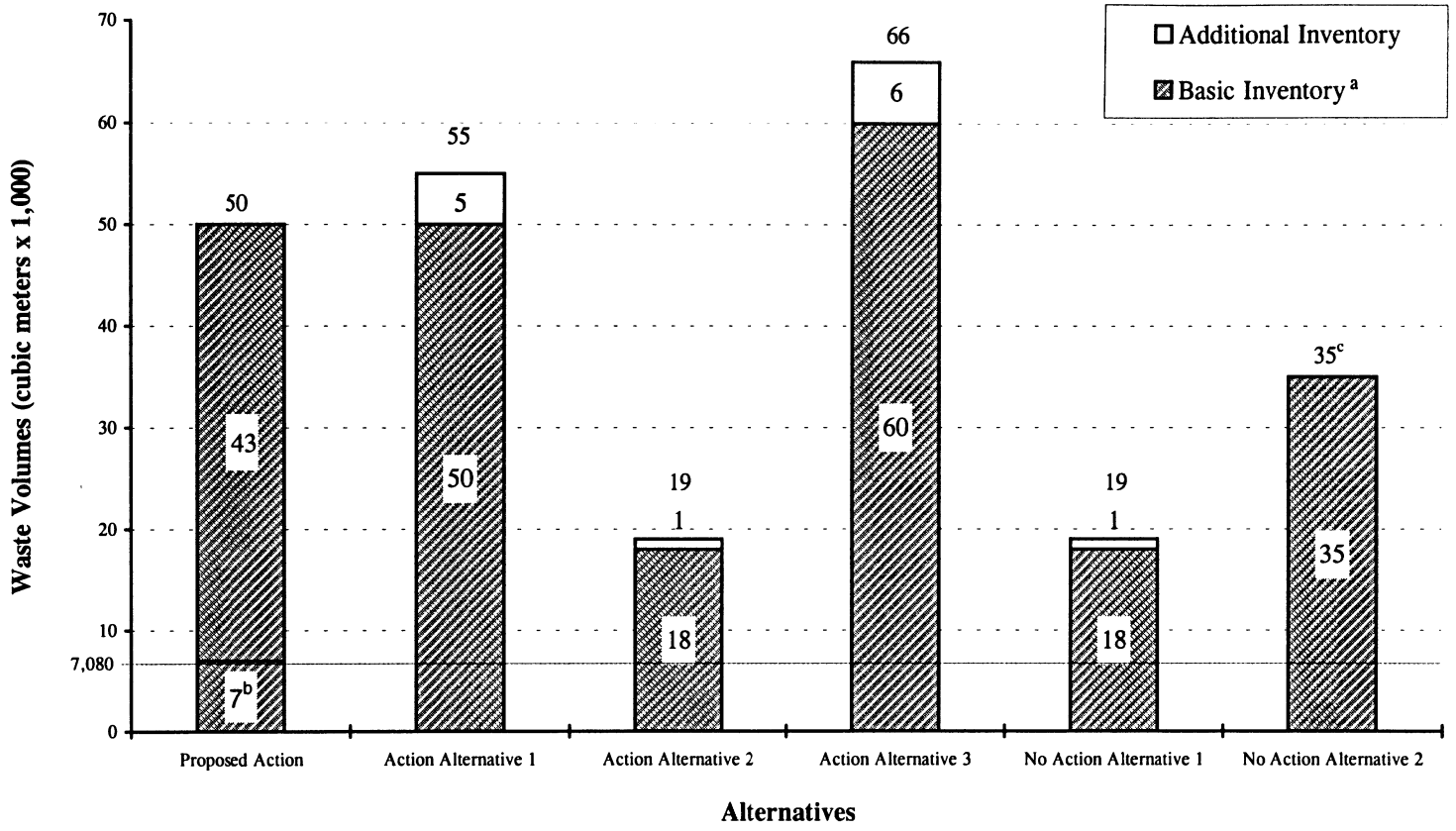
[a] The Basic Inventory consists of post-1970 and newly generated defense waste. The Basic Inventory for all alternatives has the same radionuclide inventory.

[b] The CH-TRU waste Basic Inventory is adjusted from approximately 143,000 cubic meters to 168,500 cubic meters in order to evaluate the total volume of CH-TRU waste allowable at WIPP under current laws and agreements.

[c] Includes TRU waste commingled with PCBs.

[d] Only 73,000 cubic meters of newly generated defense waste would be treated. Existing stored waste would not be treated. Therefore, the post-treatment waste volume of the Basic Inventory is not the same as for the Proposed Action and Action Alternative 1.

Figure 3-9
CH-TRU Post-Treatment Waste Volumes by Alternative



[a] The Basic Inventory consists of post-1970 and newly generated defense waste. The Basic Inventory for all alternatives has the same radionuclide inventory.

[b] Only 7,080 cubic meters of the Basic Inventory (14 percent of the Basic RH-TRU inventory) was evaluated for WIPP disposal under the Proposed Action because of the WIPP disposal limit established under the C&C Agreement with the State of New Mexico. The excess RH-TRU waste would be treated to WAC and stored at non-WIPP treatment sites.

[c] Only 32,000 cubic meters of newly generated defense waste would be treated. Existing stored waste would not be treated. Therefore, the post-treatment waste volume of the Basic Inventory is not the same as for the Proposed Action and Action Alternative 1.

Figure 3-10
RH-TRU Post-Treatment Waste Volumes by Alternative

Action Alternative 1 could result in an estimated six worker fatalities at the waste treatment sites and seven worker fatalities at WIPP. Truck transportation under Action Alternative 1 could result in an estimated additional 29 deaths (28 among members of the public). The most severe accident under this alternative would be the destruction of a storage facility as a result of a beyond-design-basis earthquake (with an annual frequency of 1×10^{-5} or less) and could result in an additional 300 deaths. The waste disposed of at WIPP under Action Alternative 1 would be isolated from the environment for more than 10,000 years, and Action Alternative 1 would effectively isolate all DOE TRU waste generated and expected to be generated over 35 years (except for a small quantity of PCB-commingled waste). Action Alternative 1 costs would be $50.95 billion in 1994 dollars ($16.32 billion when discounted), assuming truck transportation (to be comparable to the Proposed Action).

Action Alternative 2 could result in an estimated seven to twelve worker fatalities at the waste treatment sites and one to two fatalities to the populations in the vicinity of the treatment sites (with subalternatives 2A and 2B having higher impacts than subalternative 2C). An estimated six worker fatalities would result from disposal operations at WIPP under all subalternatives. Truck transportation under Action Alternative 2 could result in an estimated additional 17 to 20 deaths (16 to 19 among members of the public, with Action Alternative 2C having higher transportation impacts than Action Alternatives 2A or 2B). The most severe accident under this alternative would be the destruction of a storage facility as a result of a beyond-design-basis earthquake (with an annual frequency of 1×10^{-5} or less) and could result in an additional 480 deaths. The waste disposed of at WIPP under Action Alternative 2 would be isolated from the environment for more than 10,000 years, and Action Alternative 2 would effectively isolate all DOE TRU waste generated and expected to be generated over 35 years. Action Alternative 2 costs would range from $54.01 billion to $57.18 billion in 1994 dollars ($19.56 billion to $21.19 billion when discounted), depending on the subalternative and assuming truck transportation (to be comparable to the Proposed Action).

Action Alternative 3 could result in an estimated seven worker fatalities at the waste treatment sites and seven worker fatalities at WIPP. Truck transportation under Action Alternative 3 could result in an estimated additional 39 deaths (38 among members of the public). The most severe accident under this alternative would be the failure of the WIPP waste hoist (with an annual frequency of 4.5×10^{-7} or less) and could result in an additional 29 deaths. The waste disposed of at WIPP under Action Alternative 3 would be isolated from the environment for more than 10,000 years, and Action Alternative 3 would effectively isolate all DOE TRU waste generated and expected to be generated over 35 years (except for a small quantity of PCB-commingled waste). Action Alternative 3 costs would be $59.67 billion in 1994 dollars ($18.03 billion when discounted), assuming truck transportation (to be comparable to the Proposed Action).

No Action Alternative 1 could result in an estimated 10 to 11 worker fatalities at the waste treatment sites and 2 fatalities to the populations in the vicinity of the treatment sites (depending on the subalternative). No worker deaths would be estimated to result from closure activities at WIPP. Truck transportation under No Action Alternative 1 could result in an estimated zero deaths to workers and one death to members of the public. The most severe accident under this alternative would be the destruction of a storage facility as a result of a beyond-design-basis earthquake (with an annual frequency of 1×10^{-5} or less) and could result in an additional 480 deaths. No Action Alternative 1 would restrict access for 100 years to all DOE TRU waste generated and expected to be generated over 35 years, at which time the waste would either have to

be disposed of or a decision would have to be made to continue storage. If the waste were released, either by loss of institutional control or by natural disaster, the thermally treated waste form would restrict migration of the waste initially, but the waste would eventually become more mobile as the vitrified waste form eroded. If the waste were released, deaths to the public over 10,000 years would depend in part on population densities and distributions, but no deaths would be expected based on current densities and distributions. Future increases in population densities near TRU waste storage sites could increase the number of estimated deaths that could result from releases of TRU waste. No Action Alternative 1 costs would range from $30.28 to $32.85 billion in 1994 dollars ($17.09 to $18.54 billion when discounted), assuming truck transportation (to be comparable to the Proposed Action).

No Action Alternative 2 could result in an estimated two worker fatalities at the waste storage sites and no worker deaths from closure activities at the WIPP site. No transportation is assumed under No Action Alternative 2, and no deaths would result. The most severe accident under this alternative would be the destruction of a storage facility as a result of a beyond-design-basis earthquake (with an annual frequency of 1×10^{-5} or less) and could result in an additional 300 deaths. No Action Alternative 2 would restrict access to the currently stored and newly generated portion of DOE TRU waste for 100 years, at which time the waste would either have to be disposed of or a decision would have to be made to continue storage. If the waste were released, either by loss of institutional control or by natural disaster, estimated deaths would total 800 for the Total Inventory over 10,000 years given current population densities and distributions. Future increases in population densities near TRU waste storage sites could increase the number of estimated deaths that could result from releases of TRU waste. No Action Alternative 2 costs would be $2.49 billion in 1994 dollars ($1.68 billion when discounted).

Table 3-18 is a summary table that compares the more notable impacts from within the Proposed Action and the alternatives.

3.5 PREFERRED ALTERNATIVE

The Department's Preferred Alternative is to proceed with WIPP disposal of defense TRU waste treated to planning-basis WAC under the Proposed Action (see Section 3.1). Under the Preferred Alternative, the Department would initially transport waste by truck and would continue to explore the availability of safe and cost-effective commercial rail transportation.

The Department has identified the Proposed Action (reserving the option of future rail transportation) as its Preferred Alternative for a number of reasons, including the following: the Proposed Action would provide long-term isolation of TRU waste from the accessible environment, and the Proposed Action is consistent with DOE's obligations under agreements and court orders and with the LWA.

In contrast, the action alternatives would require amendments to the LWA and/or the C&C Agreement with New Mexico. The no action alternatives would not meet the Department's purpose and need for action, would not meet court orders and treatment plans, and would result in long-term impacts that would be avoided under the Proposed Action.

Table 3-18
Summary of SEIS-II Environmental Impacts

Consequence Category	Proposed Action/ Preferred Alternative	Action Alternative 1	Action Alternative 2A	Action Alternative 2B	Action Alternative 2C	Action Alternative 3	No Action Alternative 1A	No Action Alternative 1B	No Action Alternative 2
Land Use and Management									
Treatment Facility Sites	No substantial impacts identified beyond the treatment facilities. Treatment facilities would require no more than 11 hectares, less than 1% of land available at each site for each alternative. Treatment facilities, therefore, could be located in developed areas or areas appropriate for development. Sensitive areas, including wetlands, flood plains, sensitive habitats, and cultural resource areas would be avoided.								No substantial impacts. Only newly generated waste would be treated.
WIPP (during operations)	DOE would occupy the land transferred by the LWA and lease some other land. WIPP would continue to limit drilling and mining activities, and grazing and public access to the site and may acquire oil and gas leases. No other impacts would occur to local land use beyond the site.						Impacts would be minimal because no waste would be emplaced.		
WIPP (area impacted by closure)	70 hectares	360 hectares	395 hectares	395 hectares	395 hectares	375 hectares	20 hectares	20 hectares	20 hectares
Air Quality									
Treatment Facility Sites (As a percentage of the most stringent applicable regulatory standard. Emissions for sites and pollutants not specifically noted would be less than 10% of the most stringent applicable regulatory standard).	RFETS, CO, 17%.		LANL, radionuclides, 134%. RFETS, CO, 24%. INEEL, PM_{10} 10%.	INEEL, radionuclides, 10%. INEEL, PM_{10}, 10%.	WIPP, radionuclides, 137%. WIPP, SO_2, 12%. WIPP, PM_{10}, 25%.	RFETS, CO, 20%.	LANL, radionuclides, 134%. RFETS, CO, 24%, INEEL, PM_{10}, 10%.	INEEL, radionuclides, 10%. SRS, radionuclides, 48%. INEEL, PM_{10}, 10%.	RFETS, CO, 17%.
WIPP Operations (percent of applicable EPA or state standard)	Annual average: negligible increases of O_3 and lead; less than 2% increases in PM_{10}, NO_2, and SO_2. Short-term (24-hour) emission limits: PM_{10} - 57%, NO_2 - 65%, SO_2 - 7%, CO - 3% of standards, releases of lead and ozone would be minimal.						WIPP would not be operated. WIPP would be dismantled.		
Biological Resources									
Treatment Facility Sites	Threatened and endangered species appear at many of the proposed treatment sites and could potentially be impacted. Such species and their critical habitats would be avoided through appropriate consultation, site selection, monitoring, and mitigation measures. Because the treatment sites would require less than 1% of the land available at any site, critical habitats could be avoided at most sites.								No impacts because only minimal treatment would occur.
WIPP (disturbed land area)	Federally- or state-listed or protected, threatened, endangered, and proposed species occur in Eddy County and potentially at the WIPP site, although there have been no threatened, endangered, or proposed species or critical habitats recently observed at the WIPP site by DOE during completion of its recent biennial environmental compliance reports. DOE recently conducted biological surveys at the WIPP site and identified no endangered or threatened species. No impacts to biodiversity or ecosystem balance would be expected. Impacts to other plant and animal species may occur during closure and construction of a berm around the WIPP site. The affected area would differ based on the areas listed above under land use.						Minimal impacts during closure of current facility.		

Table 3-18
Summary of SEIS-II Environmental Impacts — Continued

Consequence Category	Proposed Action/ Preferred Alternative	Action Alternative 1	Action Alternative 2A	Action Alternative 2B	Action Alternative 2C	Action Alternative 3	No Action Alternative 1A	No Action Alternative 1B	No Action Alternative 2
Cultural Resources									
Treatment Facility Sites	Although cultural resources are present at many sites, specific treatment facility locations are unknown. Acreage need at any one site is 11 hectares or less. Potential impacts will be avoided or mitigated based on site-specific cultural resource surveys.								No impacts. Treatment would be minimal.
WIPP Resource Sites Potentially Impacted (during operations)	None.						No impacts. WIPP would not be operated.		
WIPP Resource Sites Potentially Impacted (during closure)	Two. Potential impacts would be avoided or mitigated in accordance with the Joint Powers Agreement.	Eleven due to larger surface closure area. Potential impacts would be avoided or mitigated in accordance with the Joint Powers Agreement.					No impacts for the no action alternatives. Closure would only involve the 20 acres on which current facilities have been built.		
Noise									
Treatment Sites	Negligible increase in noise due to waste transportation or treatment facility operation because treatment facilities would probably be placed at industrial-type sites along high-traffic volume corridors. Project-specific impacts to sensitive receptors could occur. Assessment of potential impacts would be conducted in site-wide or project-specific NEPA documentation.								No impacts because transportation would not occur and treatment would be minimal.
WIPP	Negligible increase in noise due to additional daily truck or train traffic. Only 8 trucks per day would travel to WIPP if trucks are used; only 13 to 16 rail cars per week if trains are used.						Not applicable to the no action alternatives. No transportation to WIPP would occur and WIPP would not be operated.		
Water Resources and Infrastructure									
Treatment Sites 1. Water 2. Power 3. Wastewater 4. On-site Transportation	3. Hanford - 5.9% 4. Hanford, INEEL, and LANL - minor impacts	2. INEEL - 6.6% 3. Hanford - 7.8% 4. Hanford, INEEL, and LANL - minor impacts	2. INEEL - 6.6% 3. Hanford - 7.8% 4. Hanford, and INEEL - minor impacts	2. INEEL - 6.6%; WIPP - 50% 3. WIPP - 80% 4. WIPP - 162%; Hanford - minor impacts	2. INEEL - 6.4% 3. Hanford - 7% 4. Hanford, INEEL, and LANL - minor impacts	2. INEEL - 6.6% 3. Hanford - 7.8% 4. Hanford, INEEL, and LANL - minor impacts	2. INEEL - 6.6% 3. Hanford - 7.8% 4. Hanford, and INEEL - minor impacts	No impacts.	
Disposal Operations at WIPP	Annual incremental infrastructure impacts at WIPP would be negligible and within capacity for disposal operations.						Decreasing use of resources, none after decommissioning of WIPP.		

Table 3-18
Summary of SEIS-II Environmental Impacts — Continued

Consequence Category	Proposed Action/ Preferred Alternative	Action Alternative 1	Action Alternative 2A	Action Alternative 2B	Action Alternative 2C	Action Alternative 3	No Action Alternative 1A	No Action Alternative 1B	No Action Alternative 2
Socioeconomics									
Treatment/Storage Sites									
Life-Cycle Costs (millions of 1994 dollars)	12,140	21,390	27,690	30,550	28,700	24,340	29,360	31,760	1,640
Annual Employment (supported jobs)	11,900	22,500	28,000	28,500	7,200	24,900	29,300	29,800	2,300
Disposal Operations at WIPP									
Life-Cycle Costs (millions of 1994 dollars)	5,300	24,650	23,330	23,330	23,330	28,490	850	850	850
Annual Goods & Services (millions of 1994 dollars)	317	317	317	317	616	317	-317	-317	-317
Annual Employment (supported jobs)	3,538	3,538	3,538	3,538	6,876	3,538	-3,538	-3,538	-3,538
Annual Labor Income (millions of 1994 dollars)	126	126	126	126	245	126	-126	-126	-126
Total Life-Cycle Cost by Mode of Transportation (millions of 1994 dollars); discounted totals using a 4.1 percent annual inflation rate are presented in parentheses									
Total Life-Cycle Costs--Truck	19,030 (10,130)	50,950 (16,320)	54,010 (19,560)	57,180 (21,190)	54,940 (20,100)	59,670 (18,030)	30,280 (17,090)	32,850 (18,520)	No shipments of TRU waste would occur under this alternative. Total life-cycle cost without transportation is 2,490 (1,680).
Total Life-Cycle Costs--Regular Rail	No rail transportation analyzed under Propsed Action; rail transportation reserved under Preferred Alternative.	47,680 (15,800)	52,030 (19,220)	55,020 (20,830)	52,940 (19,760)	55,170 (17,420)	30,240 (17,070)	32,770 (18,470)	
Total Life-Cycle Costs--Dedicated Rail		57,360 (17,330)	57,880 (20,210)	61,360 (21,900)	58,570 (20,720)	68,520 (19,210)	30,460 (17,190)	33,790 (19,040)	
Transportation									
Truck									
Number of Truck Shipments to Consolidation Sites and WIPP	CH - 29,793 RH - 8,915	CH - 41,056 RH - 66,012	CH - 43,313 RH - 30,149	CH - 51,240 RH - 30,149	CH - 41,151 RH - 30,149	CH - 67,844 RH - 82,860	CH - 538 RH - 8,254	CH - 8,466 RH - 8,254	No shipments of TRU waste would occur under this alternative.
Nonradiological Truck Impacts									
Truck Accidents	56	171	109	123	105	239	5	13	
Truck Injuries	39	119	76	86	74	165	4	12	
Truck Fatalities	5	16	10	11	11	22	0.3	1	
Truck Pollution Fatalities	0.1	0.5	0.4	0.5	0.4	0.7	0.03	0.07	

Table 3-18
Summary of SEIS-II Environmental Impacts — Continued

Consequence Category	Proposed Action/ Preferred Alternative	Action Alternative 1	Action Alternative 2A	Action Alternative 2B	Action Alternative 2C	Action Alternative 3	No Action Alternative 1A	No Action Alternative 1B	No Action Alternative 2
Radiological Truck Impacts									No shipments of TRU waste would occur under this alternative.
Accident-Free Population Impacts to Crews (LCFs)	0.3	0.7	0.5	0.7	0.5	1.0	0.02	0.07	
Accident-Free Population Impacts to the Public (LCFs)	3.0	11	6	7	6	15	0.4	0.9	
Highest Lifetime Accident-Free Impact to MEIs (probability of an LCF)	8.5E-3	8.6E-3	4.6E-3	4.9E-3	4.5E-3	9.9E-3	Not Analyzed.	Not Analyzed.	
Rail									
Nonradiological Rail Impacts	Transportation by rail not anaylzed under the Proposed Action; rail transportation is reserved under the Preferred Alternative.								
Fatalities Using Regular Rail Service		8	5	6	6	11	0.2	0.5	
Fatalities Using Dedicated Rail Service		112	70	84	84	154	2.8	7	
Radiological Rail Impacts									
Accident-Free Population Impacts to Crews (Regular and Dedicated) (LCFs)		0.03	0.03	0.03	0.03	0.05	8.6E-4	3.7E-3	
Accident-Free Population Impacts to the Public (Regular and Dedicated) (LCFs)		1.5	0.9	1	0.9	2.0	0.07	0.1	
Accidents									
Transportation Accidents (Truck)									
Population Impacts with Conservative Inventory (LCFs)	CH - 16 RH - 16	CH - 16 RH - 16	CH - <1 RH - <1	CH - <1 RH - <1	CH - 16 RH - <1	CH - 16 RH - 16	CH - 16 RH - 16	CH - 16 RH - 16	
Population Impacts with Average Inventory (LCFs)	CH - 3 RH - 0.04	CH - 3 RH - 0.04	CH - <1 RH - <1	CH - <1 RH - <1	CH - 3 RH - <1	CH - 3 RH - 0.04	CH - 3 RH - 0.04	CH - 3 RH - 0.04	
MEI Impact with Conservative Inventory (probability of an LCF)	CH - 0.06 RH - 0.06	CH - 0.06 RH - 0.06	CH - 3E-4 RH - 3E-4	CH - 3E-4 RH - 3E-4	CH - 0.06 RH - 3E-4	CH - 0.06 RH - 0.06	CH - 0.06 RH - 0.06	CH - 0.06 RH - 0.06	
MEI Impact with Average Inventory (probability of an LCF)	CH - 0.04 RH - 7E-4	CH - 0.04 RH - 7E-4	CH - 2E-4 RH - 4E-6	CH - 2E-4 RH - 4E-6	CH - 0.04 RH - 4E-6	CH - 0.04 RH - 7E-4	CH - 0.04 RH - 7E-4	CH - 0.04 RH - 7E-4	
Aggregate Potential Truck Accident Impacts to Populations Along All Transportation Routes (LCFs)	0.4	0.8	0.7	0.7	0.7	1.2	6.8E-3	0.02	

Table 3-18
Summary of SEIS-II Environmental Impacts — Continued

Consequence Category	Proposed Action/ Preferred Alternative	Action Alternative 1	Action Alternative 2A	Action Alternative 2B	Action Alternative 2C	Action Alternative 3	No Action Alternative 1A	No Action Alternative 1B	No Action Alternative 2
Transportation Accidents (Rail)									No shipments of TRU waste would occur under this alternative.
Population Impacts with Conservative Inventory (LCFs)	No rail transportation is proposed under the Proposed Action; rail transportation is reserved under the Preferred Alternative.	CH - 32 RH - 32	CH - <1 RH - <1	CH - <1 RH - <1	CH - 32 RH - <1	CH - 32 RH - 32	CH - 32 RH - 32	CH - 32 RH - 32	
Population Impacts with Average Inventory (LCFs)		CH - 6 RH - 0.08	CH - <1 RH - <1	CH - <1 RH - <1	CH - 6 RH - <1	CH - 6 RH - 0.08	CH - 6 RH - 0.08	CH - 6 RH - 0.08	
MEI Impact with Conservative Inventory (probability of an LCF)		CH - 0.12 RH - 0.12	CH - 3E-4 RH - 3E-4	CH - 3E-4 RH - 3E-4	CH - 0.12 RH - 3E-4	CH - 0.12 RH - 0.12	CH - 0.12 RH - 0.12	CH - 0.12 RH - 0.12	
MEI Impact with Average Inventory (probability of an LCF)		CH - 0.08 RH - 1E-4	CH - 2E-4 RH - 4E-6	CH - 2E-4 RH - 4E-6	CH - 0.08 RH - 4E-6	CH - 0.08 RH - 1E-4	CH - 0.08 RH - 1E-4	CH - 0.08 RH - 1E-4	
Aggregate Potential Rail Accident Impacts (LCFs) to Populations Along All Rail Routes		0.8	0.7	0.7	0.7	1.2	6.8E-3	0.02	
Human Health									
Routine Radiological Impacts (LCFs) [a]									
Treatment									
Involved Worker Population	0.8	1.5	1.7	1.3	0.6	1.5	1.7	1.3	0.4
Noninvolved Worker Population	7E-6	8E-6	0.1	0.1	0.06	7E-4	0.1	0.1	8E-5
Maximum Exposed Noninvolved Worker	3E-9	8E-9	5E-5	2E-4	2E-4	2E-7	5E-5	2E-4	4E-8
Public Population	2E-4	2E-4	2.4	2.3	0.9	4E-3	2.4	2.3	1E-3
MEI	9E-9	1E-9	3E-5	5E-5	2E-4	4E-7	3E-5	5E-5	8E-8
WIPP Operations [b] **(LCFs) [a]**							**Storage Impacts at Treatment Sites Only - No WIPP Operations**		
Involved Worker Population	≤1	≤1	<0.4	<0.4	<0.4	0.3	≤1.1	≤1.1	≤3
Noninvolved Worker Population	4E-4	5E-4	2E-4	2E-4	2E-4	5E-4	0.06	0.06	0.1
Maximum Exposed Noninvolved Worker	4E-7	4E-7	2E-7	2E-7	2E-7	3E-7	1E-6	1E-6	4E-5
Public Population	3E-4	4E-4	5E-5	5E-5	5E-5	3E-4	3E-3	2E-3	0.03
MEI	3E-7	5E-7	1E-7	1E-7	1E-7	3E-7	2E-7	2E-9	2E-6
Lag Storage[c] Public Population Impacts	No lag storage for the Proposed Action.	1E-2	1E-3	8E-4	3E-4	3E-3	No lag storage for the no action alternatives.		
Lag Storage Noninvolved Worker Population		0.05	2E-2	2E-2	1E-3	0.07			
Excess RH-TRU Waste Storage Public Population Impacts[d]	2E-5	No excess RH-TRU waste is considered in these alternatives; such RH-TRU waste is reflected in the inventory/waste volumes for these alternatives.							
Excess RH-TRU Waste Storage Noninvolved Worker Population[d]	4E-5								

Table 3-18
Summary of SEIS-II Environmental Impacts — Continued

Consequence Category	Proposed Action/ Preferred Alternative	Action Alternative 1	Action Alternative 2A	Action Alternative 2B	Action Alternative 2C	Action Alternative 3	No Action Alternative 1A	No Action Alternative 1B	No Action Alternative 2
Routine Hazardous Chemical Impacts (Cancer Incidence)									
Treatment at Treatment Sites									
Involved Worker Population	2E-5	3E-5	6E-5	9E-5	8E-5	4E-5	6E-5	9E-5	8E-6
Noninvolved Worker Population	1E-7	2E-7	1E-7	1E-7	1E-7	2E-7	1E-7	1E-7	1E-7
Maximum Exposed Noninvolved Worker	1E-10	2E-10	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10
Public Population	4E-7	6E-7	3E-7	3E-7	3E-7	4E-7	3E-7	3E-7	4E-7
Maximum Exposed Individual	2E-11	3E-11	2E-11	2E-11	2E-11	2E-11	2E-11	2E-11	2E-11
WIPP Operations [a]							**Storage Impacts at Treatment Sites Only - No WIPP Operations**		
Involved Worker Population	0.01	0.04	No impacts because the TRU waste would be thermally treated.			≤0.01	None because TRU waste would be thermally treated.		≤0.1
Noninvolved Worker Population	1E-4	1E-4				9E-5			6E-3
Maximum Exposed Noninvolved Worker	1E-7	9E-8				5E-8			2E-7
Public Population	2E-5	3E-5				2E-5			6E-3
Maximum Exposed Individual	3E-8	2E-8				1E-8			4E-8
Lag Storage[c] Public Population	No lag storage for the Proposed Action.	5E-3				4E-3	None because there is no lag storage for the no action alternatives.		
Lag Storage Noninvolved Worker Population		0.01				0.02			
Excess RH-TRU Waste Storage Public Population Impacts[d]	3E-4	No excess RH-TRU waste is considered in these alternatives; such RH-TRU waste is reflected in the inventory/waste volumes for these alternatives.							
Excess RH-TRU Waste Storage Noninvolved Worker Population[d]	6E-4								
Selected Facility Accidents [a]									
Treatment Facility Sites (Earthquake) LCFs									
Maximally Exposed Noninvolved Worker	0.01	0.01	1	1	1	0.02	1	1	0.01
Maximally Exposed Individual	2E-3	2E-3	1	1	1	5E-3	1	1	2E-3
Public Population	3	3	480	480	28	6	480	480	3
Storage Facility Sites (Earthquake) LCFs									
Maximally Exposed Noninvolved Worker	3E-3	1.0	0.05	0.05	0.1	0.04	0.02	0.02	0.7
Maximally Exposed Individual	5E-4	0.1	5E-3	5E-3	0.08	5E-3	0.08	0.08	0.1
Public Population	0.9	300	10	9	2	10	10	10	300
WIPP Disposal (Hoist Failure, frequency of 4.5E-7) LCFs									
Maximally Exposed Noninvolved Worker	0.06	0.06	0.5	0.5	0.5	0.5	No impacts because disposal does not occur under the no action alternatives.		
Maximally Exposed Individual	0.08	0.08	0.6	0.6	0.6	0.6			
Public Population	5	5	29	29	29	29			

Table 3-18
Summary of SEIS-II Environmental Impacts — Continued

Consequence Category	Proposed Action/ Preferred Alternative	Action Alternative 1	Action Alternative 2A	Action Alternative 2B	Action Alternative 2C	Action Alternative 3	No Action Alternative 1A	No Action Alternative 1B	No Action Alternative 2
Industrial Safety									
Waste Treatment (fatalities)	4	4	9	7	6	5	9	7	0.7
Construction and Operations (fatalities)	2	6	6	6	6	7	0.8	0.8	0.6
Performance Assessment of Treatment Sites and WIPP									
Treatment Sites - Human Intrusion [e]									
Radiological Impacts (probability of an LCF)									
Driller	4E-4 [f]	Does not apply to these alternatives because there is no waste at the treatment sites under the action alternatives, and TRU waste is managed indefinitely under No Action Alternatives 1A and 1B.							1E-6 to 3E-5
Gardener	3E-3 [f]								4E-3 to 0.06
Scavenger	0.01 [f]								6E-4 to 0.02
Family Farm	1 [f]								0.2 to 1
Treatment Sites - Environmental Release									
Radiological Impacts (probability of an LCF)									
MEI (probability of an LCF)	5E-5 [f]	Does not apply to these alternatives because there is no waste at the treatment sites under the Proposed Action and the action alternatives. For No Action Alternatives 1A and 1B, it was assumed the waste would be managed indefinitely.							3E-6 to 4E-3
Population (LCFs)	3E-4 [f]								4E-5 to 7
Aggregate Population Impacts over 10,000 years	4E-3 [f]	Does not apply to these alternatives because there is no waste at the treatment sites.					8E-4	3E-4	807
Hazardous Chemical Impacts (Cancer Incidence)									
MEI	9E-7 [f]	Does not apply to these alternatives because there is no waste at the treatment sites under the action alternatives, and TRU waste is managed indefinitely under No Action Alternative 1.							1E-7 to 5E-3
Population	5E-6 [f]								5E-7 to 3E-4
WIPP - Human Intrusion (based on the intrusion in the repository scenario)									
Maximum Radiological Impacts Drilling Crew Member (probability of an LCF; dashes indicate no analyses were performed because scenarios are inapplicable)									
CH-TRU Waste Panel	---	4E-4	1E-4	1E-4	1E-4	3E-4	Does not apply to these alternatives. No waste would be disposed of at WIPP.		
RH-TRU Waste Panel	---	1E-5	2E-6	2E-6	2E-6	1E-5			
Mixed CH-TRU and RH-TRU Panel	4E-4	4E-4	---	---	---	3E-4			
Maximum Radiological Impacts Site Geologist (probability of an LCF)									
CH-TRU Waste Panel	3E-9	3E-9	7E-9	7E-9	7E-9	2E-9	Does not apply to these alternatives. No waste would be disposed of at WIPP.		
RH-TRU Waste Panel	3E-9	5E-9	1E-8	1E-8	1E-8	4E-9			
Environmental Justice									
Treatment sites and WIPP	Although possible, disproportionately high and adverse effects on minority or low-income populations are not expected.				Impacts are possible at WIPP during treatment.	Although possible, disproportionately high and adverse effects on minority or low-income populations are not expected.			

Table 3-18
Summary of SEIS-II Environmental Impacts — Continued

Consequence Category	Proposed Action/ Preferred Alternative	Action Alternative 1	Action Alternative 2A	Action Alternative 2B	Action Alternative 2C	Action Alternative 3	No Action Alternative 1A	No Action Alternative 1B	No Action Alternative 2
TRU Waste Retrieval (of one panel of waste before repository closure)									
Population Exposures (LCFs)									
Involved Worker Population	0.03	0.03	0.03	0.03	0.03	0.03	Does not apply to these alternatives. No waste would be disposed of at WIPP.		
Noninvolved Worker Population	4E-5	4E-5	4E-5	4E-5	4E-5	4E-5			
Public Population	3E-5	3E-5	3E-5	3E-5	3E-5	3E-5			
Transportation									
Accident-Free Population Impacts to Crews (LCFs)	0.03	0.03	0.03	0.03	0.03	0.03	Does not apply to these alternatives. No waste would be disposed of at WIPP.		
Accident-Free Population Impacts to the Public (LCFs)	0.3	0.3	0.3	0.3	0.3	0.3			
Traffic-Related Fatalities	0.5	0.5	0.5	0.5	0.5	0.5			
TRU Waste Recovery (of all waste after repository closure)									
Population Exposures (LCFs)									
Involved Worker Population	8	8	8	8	8	8	Does not apply to these alternatives. No waste would be disposed of at WIPP.		
Noninvolved Worker Population	0.3	0.3	0.3	0.3	0.3	0.3			
Public Population	0.2	0.2	0.2	0.2	0.2	0.2			
Transportation									
Accident-Free Population Impacts to Crews (LCFs)	1	1	1	1	1	1	Does not apply to these alternatives. No waste would be disposed of at WIPP.		
Accident-Free Population Impacts to the Public (LCFs)	15	15	15	15	15	15			
Vehicle Emission Effects Fatalities	7	7	7	7	7	7			
Traffic-Related Fatalities	185	185	185	185	185	185			

[a] The probability of an LCF occurring to the MEI or maximum exposed noninvolved worker, and the number of LCFs to the populations.

[b] Under the no action alternatives, this category represents impacts from storage.

[c] Lag storage is storage pending shipment to WIPP. Lag storage does not include long-term storage of waste (such as any excess RH-TRU waste under the Proposed Action) that will not be shipped to WIPP.

[d] Recent estimates in the *National Transuranic Waste Management Plan* indicate there would be no excess RH TRU waste; see Appendix J.

[e] People who might intrude upon the stored waste could receive radiation doses that would greatly exceed current regulatory limits.

[f] Impacts from any excess RH-TRU waste. Scaled from No Action Alternative 2.

Note: For details on impacts due to the Additional Inventory (for the Proposed Action) see the text box "The Additional Inventory and the Proposed Action." For information on how impacts would change should WIPP's operations period be reduced to 175 years or less, see the text box "Reducing Operations Periods."

3.6 REFERENCES CITED IN CHAPTER 3

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CHAPTER 4
DESCRIPTION OF THE AFFECTED ENVIRONMENTS

This chapter describes the affected environments at the Waste Isolation Pilot Plant (WIPP) site and at the ten major generator-storage sites. The WIPP site is discussed in detail with emphasis on the changes that have occurred and new information that has been determined since the publication of the *Final Supplement Environmental Impact Statement for the Waste Isolation Pilot Plant* (SEIS-I) in 1990 (DOE 1990).

4.1 EXISTING ENVIRONMENT AT THE WIPP

The passage of the WIPP Land Withdrawal Act (LWA), results of recent environmental studies, and changes to various aspects of the existing environment have generated new information concerning the environment at the WIPP site. The following sections update Sections 4.1.1 through 4.3.5 of SEIS-I (DOE 1990).

4.1.1 Land Use and Management

The U.S. Department of Energy (DOE or the Department) defines the region of influence (ROI) for land use impacts as WIPP plus ". . . the site and the area immediately adjacent to the site" (DOE 1997b).[1] Thus, for WIPP, the area of consideration for land use includes privately owned ranches and Bureau of Land Management (BLM) lands, including some leased as mineral and grazing lands immediately adjacent to the WIPP site. The *Final Environmental Impact Statement for the Waste Isolation Pilot Plant* (FEIS) (DOE 1980) states that almost 7,700 hectares (19,000 acres) of land surrounding WIPP were committed to the WIPP project. It notes that the dominant use of the land within 16 kilometers (10 miles) of the site is grazing, with lesser amounts used for oil and gas extraction and potash mining. BLM owns most of this land. Two ranches are located within 16 kilometers (10 miles)

CHANGES IN SITE LAND USE AND MANAGEMENT

Since publication of SEIS-I, DOE has made the following changes in land use. These changes are largely due to the planning-basis WIPP Waste Acceptance Criteria (WAC) and the Land Management Plan.

- *Wildlife Management* - DOE initiated a multi-year research effort to document the population and ecology of several species, and additional seeding of reclamation sites was undertaken.
- *Cultural Resources Management* - DOE created a comprehensive WIPP archeological database.
- *Vegetation Management* - DOE now monitors vegetation for evidence of stress induced by climate and salt tailings.
- *Rights-of-Way* - In 1994, DOE requested and was granted permission by BLM to construct a short access road.
- *Emergency and Facility Security* - DOE has published three plans on emergency and facility security.
- *Groundwater Surveillance* - DOE has installed seven new wells to monitor water quality.

[1] Currently this ROI includes only two working ranches. No towns are included.

of the WIPP site while the closest town, Loving, New Mexico, is 29 kilometers (18 miles) away. The federal government or the State of New Mexico owns most of the land within 50 kilometers (30 miles) of the WIPP site. Within 80 kilometers (50 miles) of the site, there is dryland farming, irrigated farming along the Pecos River, and some forest, wetland, and urban land (see Figure 4-1).

SEIS-I (DOE 1990) notes the release of approximately 4,450 hectares (11,000 acres) of previously restricted land for unrestricted use, allowing exploration for and development of mineral resources and permanent habitation. It describes a land withdrawal boundary, which defines the WIPP site, as encompassing 16 sections (4,146 hectares [10,240 acres]) of federal land in Township 22 South, Range 31 East (Figure 4-2). This boundary was delineated so as to extend at least 1.6 kilometers (1 mile) beyond any WIPP underground development.

The type of land use surrounding WIPP has not changed substantially since the preparation of SEIS-I, although the level of development has increased. The site has been divided into four areas under DOE control (Figure 4-2). A chain-link fence surrounds the innermost "Property Protection Area," which includes the surface facilities. Surrounding this inner area is the "Exclusive Use Area," set off by a barbed-wire fence. Enclosing these areas is the "Off-Limits Area," which is unfenced to allow livestock grazing but, like the other two, is patrolled and posted against trespass or other land uses. Beyond the "Off-Limits Area," but within the 16-section WIPP site, the land is managed under the traditional public land use concept of multiple use. Mining and drilling for purposes other than support of the WIPP project, however, are restricted (DOE 1995d).

On October 30, 1992, the President signed into law the LWA (Public Law 102-579). This Act transferred responsibility for management of the WIPP withdrawal area from the Secretary of the Interior to the Secretary of Energy. The land is permanently withdrawn from all forms of entry, appropriation, and disposal under the public land laws and is reserved for uses associated with the purposes of WIPP. LWA establishes certain rights and responsibilities, one of which was the preparation of a Land Management Plan published in 1993 (DOE 1993a).

DOE's WIPP Land Management Plan incorporates the restrictions of the LWA and the DOE Memorandum of Understanding (MOU) with the BLM. The Land Management Plan establishes management objectives and planned actions for the use of the withdrawn land until the end of the decommissioning phase. The plan promotes the concept of multiple-use management for the surface area of the withdrawn land and establishes a goal of minimizing land use restrictions where possible. The plan also provides opportunity for participation in the land use planning process by the public, and local, state, and federal agencies.

The Land Management Plan lists 13 areas of concern: wildlife, cultural resources, grazing management, recreation, mining and oil and gas production, rights-of-way, access, emergency and facility security, fire management, water service, groundwater surveillance, salt tailings, and reclamation. The following is a summary of the progress made toward implementing this plan. Details of these actions can be found in the *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1994* (DOE 1995d).

Recent efforts in the area of wildlife management include initiating a multi-year research investigation into the ecology and life history of resident raptor populations, with emphasis on the Harris hawk (*Parabuteo unicinctus*); appraisals of populations of small nocturnal mammals; and the additional seeding of reclamation sites to increase soil stabilization.

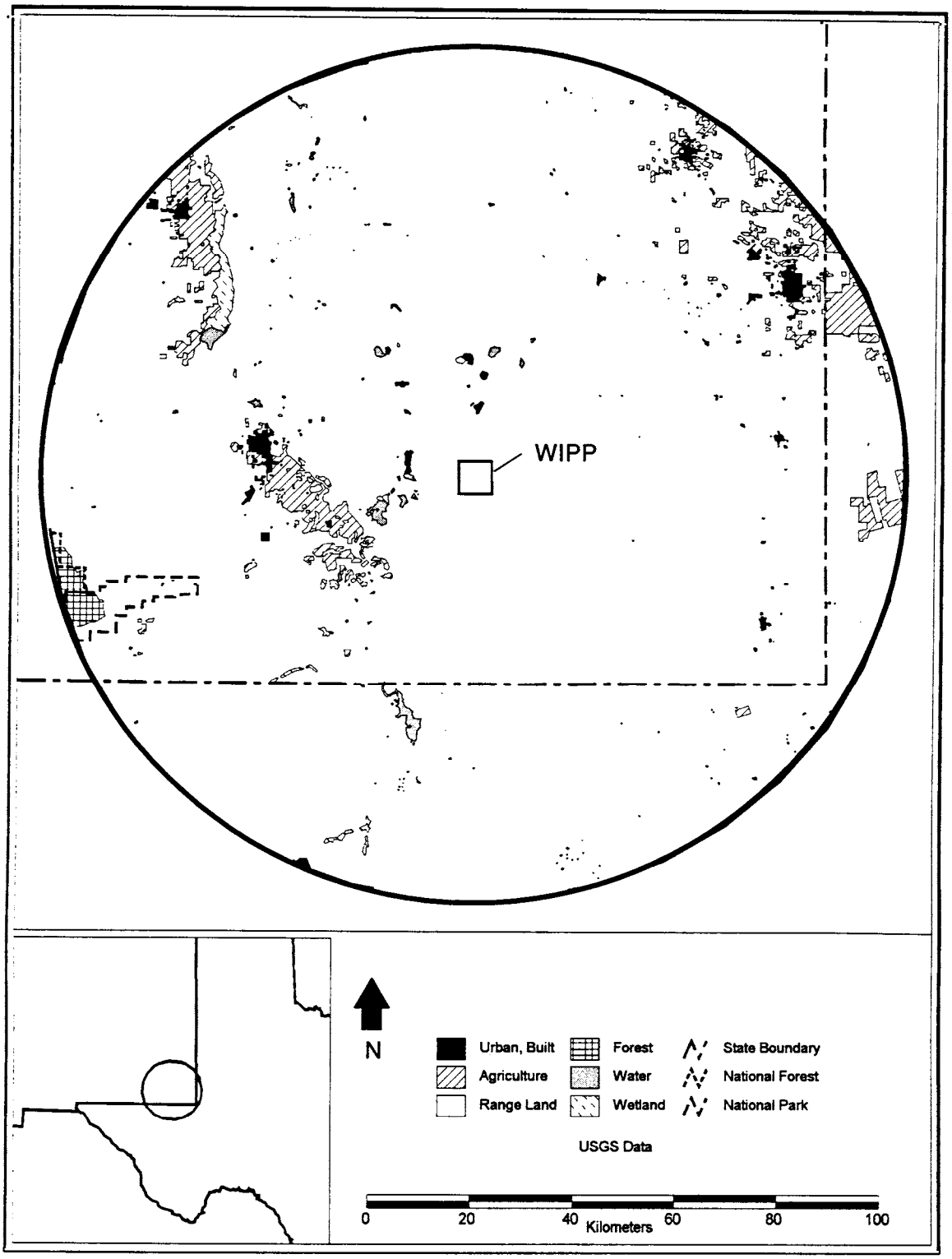


Figure 4-1
Land Use Within 80 Kilometers (50 Miles) of WIPP

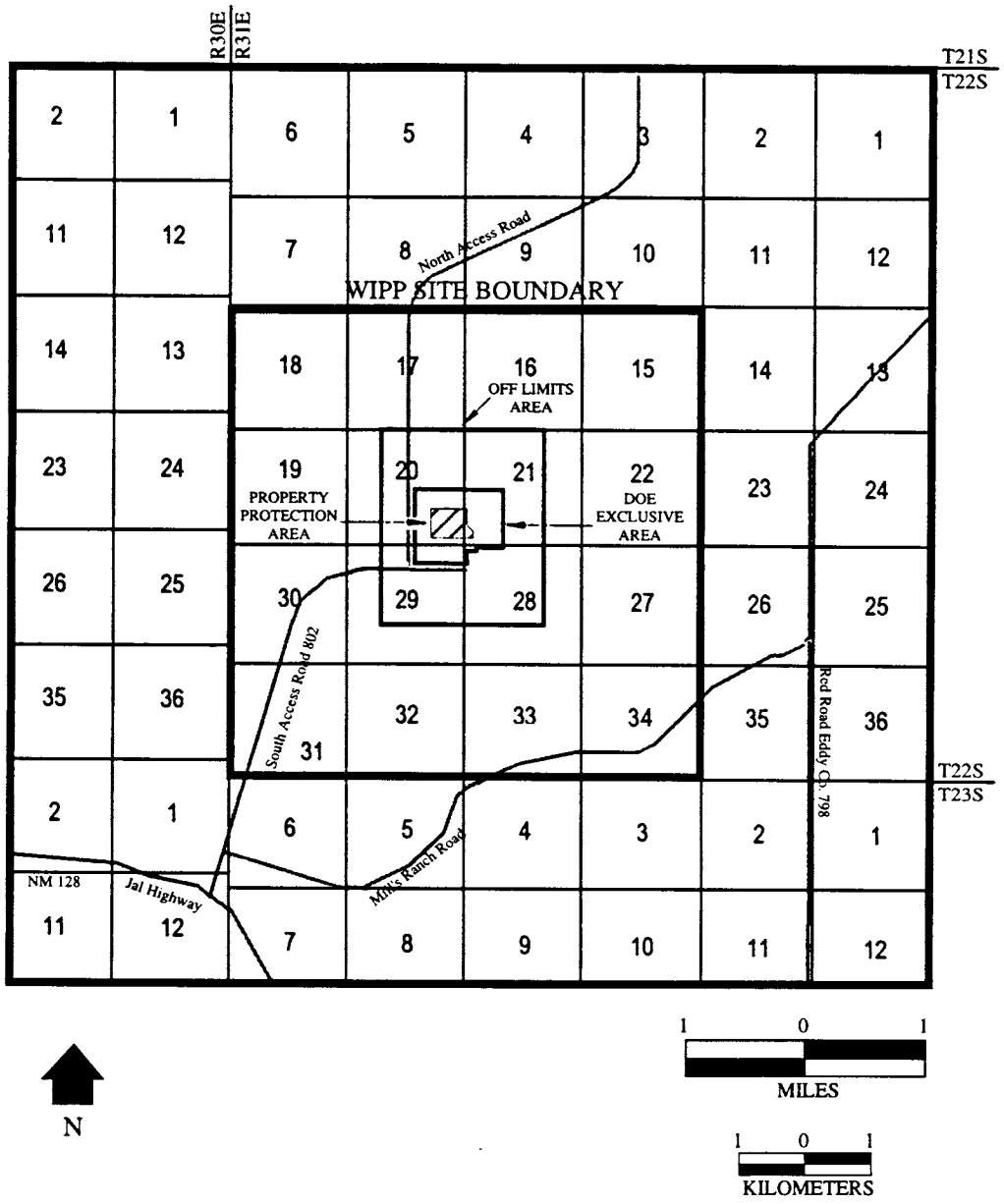


Figure 4-2
WIPP Areas

DOE also recently entered into a Joint Powers Agreement with the State of New Mexico (signed by the State Historic Preservation Officer), pursuant to Sections 106 and 110 of the National Historic Preservation Act and other statutes.

DOE's intent concerning grazing management is to continue current management practices unless a need develops to modify them. To that end, planned actions include continuing vegetative monitoring in the withdrawal area, continuing the management of grazing allotments under the principles of multiple-use management and sustained yield, and continuing range management practices in accordance with appropriate acts and regulations.

DOE intends to maintain recreation resource values and to continue to provide opportunities for individuals to participate in recreational activities within designated parts of the withdrawal area. Planned actions include environmental monitoring of the withdrawal area, regulating off-road vehicle use, and determining the potential effect of anticipated projects or other activities on the visual quality of the landscape. DOE would also allow hunting and trapping in accordance with applicable regulations.

The Land Management Plan incorporates the restrictions of the LWA. The subsurface of the withdrawal area is reserved for exclusive use of WIPP. No surface or subsurface mining unrelated to the WIPP project, including slant drilling from outside the boundary area, is permitted. The exception is two tracts of land within the withdrawal area that are leased from BLM for oil and gas development below 1,829 meters (6,000 feet). In instances where operators seek permits to drill or mine at a location close to the withdrawal boundary, DOE will request drilling information to detect any potential for subsurface encroachment into the WIPP repository. Should there be potential for encroachment, the operator will be required to modify the drilling activity in accordance with existing memorandums of understanding or similar agreements. Two active mining and drilling leases within the Land Withdrawal Area may be purchased by DOE.

BLM administers rights-of-way in coordination with DOE. The objective is to ensure safe and adequate access to WIPP while protecting the security of personnel and facilities. Consideration is also being given to closing parts of some access roads to protect the health and safety of the public. In 1994, DOE requested and was granted permission to construct short access roads from main roadways to the sites of wells.

Changes concerning emergency and facility security preparedness include implementing plans to minimize impacts during emergencies. These plans include the WIPP Emergency Plan (WP 12-9), the WIPP Resource Conservation and Recovery Act (RCRA) Contingency Plan (WP 02-12), and the WIPP Security Plan.

Fire management is concerned with wildfires in the withdrawal area. The Land Management Plan provides for immediate notification of the BLM Carlsbad Fire Control Officer upon detection of a wildfire. WIPP personnel may call upon help from various sources or may opt to have BLM fight a wildfire, if conditions warrant that choice.

Water service for WIPP is provided by a DOE-constructed water line from Carlsbad's system to the WIPP site and is made possible by a contract between DOE and the City of Carlsbad.

The groundwater surveillance program adjusts surveillance activities, if necessary, and plugs and seals wells when they are no longer necessary. In support of this program, seven new wells were installed for water quality sampling.

The Land Management Plan provides for the management of the salt pile in an environmentally sound manner until such time as a determination is made on its disposition. Salt backfill is not required for subsidence control or repository performance but may be placed into the repository for final disposition. Management of the salt pile may include monitoring vegetation for evidence of stress from salt; selling or disposing of unneeded salt under the Materials Act of 1947; ripping, leveling, and adding topsoil to the salt stockpile base; and reseeding with seed mixes reflecting indigenous plant species.

Recent activities in the area of land reclamation have included decommissioning numerous fenced areas, removing rebar from study areas to alleviate safety hazards to personnel and livestock, and carrying out additional reclamation measures in selected problem areas such as drainages and eroded slopes.

4.1.2 Air Quality, Climate, and Noise

The Environmental Protection Agency (EPA) has classified Eddy County, New Mexico, where WIPP is located, as an attainment area for all six of the criteria pollutants under the National Ambient Air Quality Standards (NAAQS). WIPP is also in a Class II Prevention of Significant Deterioration (PSD) area, and any new sources of emissions would have to adhere to the standards for such an area (META/Berger 1995). The Class I PSD areas nearest to WIPP are: Carlsbad Caverns National Park, which is approximately 61 kilometers (38 miles) southwest of WIPP, and Guadalupe Mountains National Park, which is approximately 100 kilometers (62 miles) southwest of WIPP.

The measurement of selected air pollutants at WIPP began in 1976 and was reported in FEIS (DOE 1980). SEIS-I (DOE 1990) stated that seven classes of EPA-regulated atmospheric gases had been monitored since August 27, 1986. These gases are carbon monoxide (CO), hydrogen sulfide (H_2S), ozone (O_3) precursors, oxides of nitrogen (NO_x), and sulfur dioxide (SO_2). Total suspended particulates (TSP) were also monitored in conjunction with the air monitoring programs of EPA's Regulatory and Environmental Surveillance Programs. As reported in SEIS-I, the results of this monitoring program indicated that air quality in the area of WIPP usually met state and federal standards. SEIS-I indicated that, during periods of high wind and blowing sands, the TSP standards were occasionally exceeded, but the ambient air quality standard for sulfur dioxide had been infrequently exceeded.

Air quality monitoring data collected since 1990 are summarized in annual WIPP site

CHANGES IN AIR QUALITY MONITORING

Since publication of SEIS-I, the following changes have occurred:

- *Monitoring of Pollutant Gases* - On October 30, 1994, after DOE notified EPA, monitoring of criteria air pollutants at the WIPP Ambient Air Monitoring Station was discontinued because it was no longer required by regulation.
- *Volatile Organic Compound (VOC) Monitoring Program* - The VOC monitoring program was established at WIPP in 1991 after the EPA determined that air migration of VOC target compounds would be a potential concern during both testing and operations at the facility.

environmental reports (DOE 1992, 1993b, 1994a, 1995d, and 1996d). WIPP has completed inventories of potential pollutants and emissions in accordance with EPA and New Mexico Air Quality Control Regulations (AQCR). Based on these inventories, WIPP has no permitting or reporting requirements at this time except for those applying to two primary backup diesel generators. An AQCR operating permit was issued for the two diesel generators in 1993 (DOE 1995d). These diesel generators are assumed to emit four pollutants (nitrogen dioxide (NO_2), SO_2, CO and particulate matter less than or equal to 10 micrometers in diameter [PM_{10}]) and have strict limits on emissions for these pollutants (see Section C.3.2). On October 30, 1994, DOE, after notifying EPA, ceased to monitor criteria air pollutants at the WIPP Ambient Air Monitoring Station because there was no longer a regulatory requirement to do so. TSP monitoring continues weekly at off-site locations.

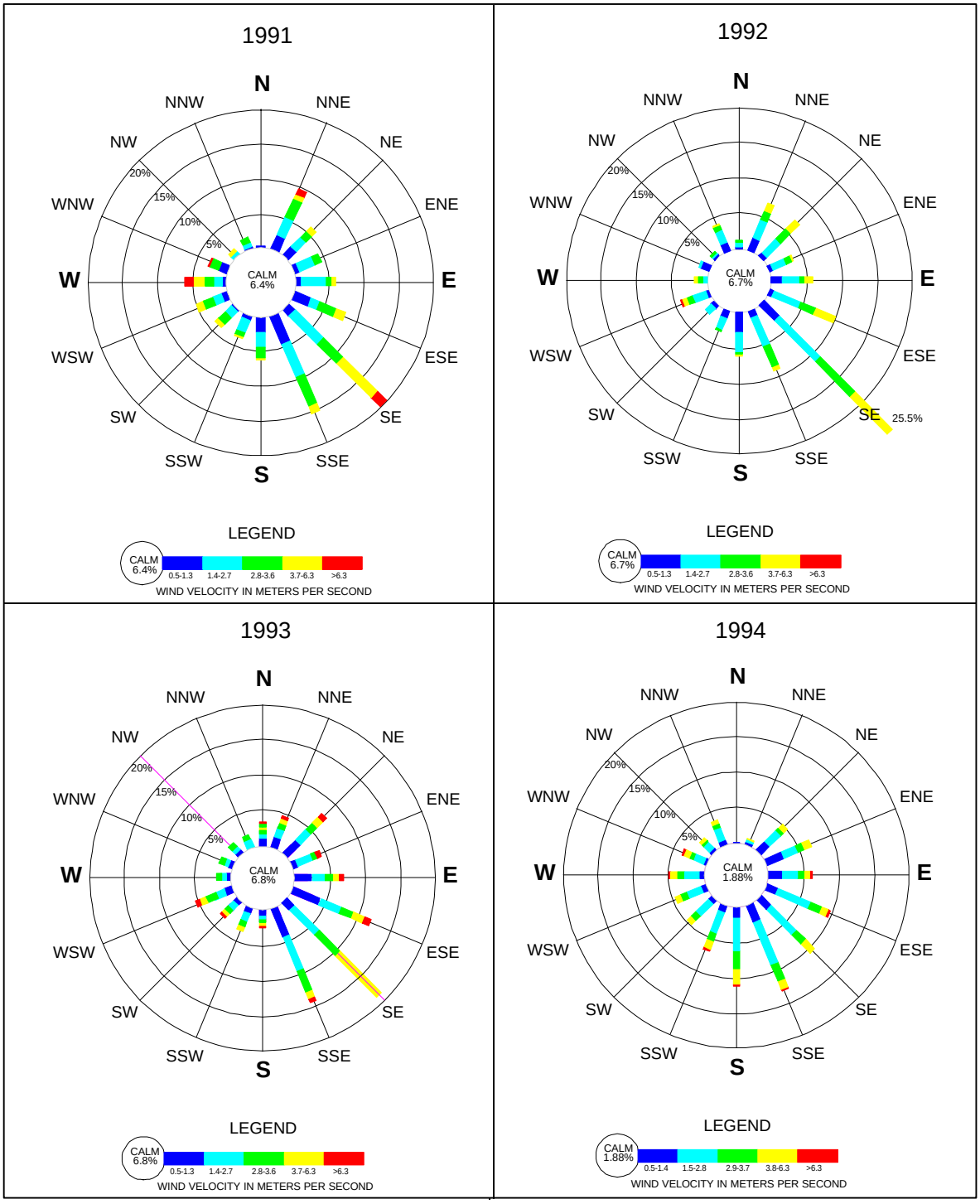
In 1991, after the EPA determined that air migration of VOCs would be a potential concern during testing at the facility, the VOC monitoring program was established at WIPP, and five VOC sampling stations were installed. The VOC monitoring program consisted of monitoring the air pulled from the exhaust shaft for any VOCs released from the test wastes. Samples were regularly analyzed for five target VOCs (carbon tetrachloride, methylene chloride, trichloroethylene, trichloroethane, and freon-113), and for other organics that might be detected.

Background monitoring of target VOCs will continue at three of the five locations. One location will measure the target compounds in the exhaust stream near the top of the exhaust shaft, another will sample the ambient air drawn into the underground facility, and the third will measure the background concentration. By measuring VOCs at the three locations it will be possible to define the variability in VOC concentration due to WIPP operations.

The regional climate is semiarid, with low precipitation and humidity and a high rate of evaporation. Precipitation is unevenly distributed throughout the year, with most occurring during summer thunderstorms. Winds are mostly from the southeast and moderate. In late winter and spring, there are strong west winds and dust storms. Thunderstorms are frequent from June through September, and are often accompanied by hail. Rains are brief but occasionally intense and can result in flash flooding in arroyos and along floodplains. Tornadoes are common throughout the region. From 1955 through 1967, 15 tornadoes were reported in the WIPP site area covered by one degree of latitude and longitude (DOE 1980).

The Carlsbad Air Terminal is the closest meteorological monitoring station and is located approximately 50 kilometers (30 miles) west of WIPP. Because of the relatively flat terrain, meteorological measurements at the airport are considered to be representative of the region. The mean annual temperature is 16 degrees Celsius (60 degrees Fahrenheit), and the mean annual precipitation is about 33 centimeters (13 inches). Drought conditions occurred during 1994. Precipitation for the 1994 calendar year was 31 percent less than that of the 1993 calendar year and 74 percent less than that of the 1992 calendar year.

The predominant wind direction at WIPP during calendar years 1991 through 1993 was from the southeast. However, during the 1994 calendar year, winds during late spring were primarily from the west. Wind speeds categorized as calm (less than 0.5 meters [1.6 feet] per second) usually occur about 7 percent of the time. Wind speeds of 1.4 through 2.7 meters (4.6 through 8.9 feet) per second were the most prevalent in the 1994 calendar year, occurring 25.5 percent of the time. Figure 4-3 displays the 1991 through 1994 wind roses (DOE 1992, 1993b, 1994a, and 1995d).



Source: DOE 1992, 1993b, 1994a, and 1995d

Figure 4-3
Windroses for 1991-1994

These conditions are consistent with long-term averages for the region. For a comprehensive discussion of climatology at the WIPP site, see Section 7.1.1 of the FEIS (DOE 1980). The WIPP site annual environmental reports (DOE 1991, 1992, 1993b, 1994a, 1995d, and 1996d) provide monthly and annual temperatures, precipitation, and wind conditions.

The ambient noise level in the WIPP area prior to construction was 26 to 28 decibels (DOE 1980). DOE requires its facilities to comply with Occupation Safety and Health Administration standards as promulgated in Title 29, of the Code of Federal Regulations (CFR), Section 1910.95. Any WIPP noise sources with the potential to exceed these standards have been mitigated (for example, noise dampers have been installed in the underground air exhausts) and are now in compliance with 29 CFR Section 1910.95.

4.1.3 Geology and Hydrology

KEY ELEMENTS CONCERNING GEOLOGY AND HYDROLOGY

Since publication of SEIS-I, additional studies and analyses have provided new information regarding geology and hydrology. These studies have improved the understanding of processes considered in evaluating long-term performance. Several examples are listed below:

- Extensive testing of the Salado Formation's salt beds and interbeds has resulted in confirmation of the Salado's extremely low permeability.
- Recent test data have enabled improved predictions of pressures at which Salado interbeds will likely fracture and relieve elevated gas pressures within the repository.
- Refined modeling of gas generation suggests that elevated gas pressure may slow down or stop brine inflow, thereby slowing gas-generating processes.
- Three-dimensional modeling of groundwater flow in the Rustler Formation suggests a very small amount of vertical flow and a preponderance of horizontal flow within the Culebra Dolomite.
- Recent tests on the Culebra Dolomite have provided new data on contaminant transport in the Culebra and on the Culebra's potential to retard radionuclides.

The first part of this section summarizes the geological and hydrological features of the WIPP site as well as key factors relevant to the repository's ability to isolate waste (repository performance). The remainder provides a discussion of what has been learned since SEIS-I. For the interested reader, there are several WIPP documents containing detailed, comprehensive, and technical descriptions of WIPP geology and hydrology. These documents have been incorporated by reference. Among them are FEIS (DOE 1980), SEIS-I (DOE 1990), the *Preliminary Performance Assessment for the Waste Isolation Pilot Plant* done by Sandia National Laboratories (SNL) (SNL 1992), the *Final No-Migration Variance Petition* (DOE 1996a), the *Waste Isolation Pilot Plant Safety Analysis Report* (DOE 1997a), and the *Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant* (DOE 1996c). These references are cited throughout this section.

The geophysical, geochemical, and hydrological behavior of various strata believed to be important to WIPP performance has been investigated during almost 20 years as a part of the WIPP program. Since SEIS-I, most of the research performed has centered on improving understanding of groundwater flow and transport processes. This research has primarily dealt with: (1) hydraulic testing of the Salado Formation and characterization of brine flow within the Salado; (2) modeling of the interactions among gas generation, brine flow into the repository, and contaminated brine flow out of the repository; (3) modeling of regional groundwater flow in units above and below the Salado, particularly the Rustler Formation, which overlies the Salado and includes the Culebra

Dolomite; (4) hydraulic testing and tracer testing within the Culebra Dolomite; (5) characterization and modeling of hydrologic and geochemical characteristics of the Culebra; and (6) geophysical characterization of the pressurized brine occurrences in the Castile Formation that underlies the Salado. The following section summarizes results of investigations of WIPP geology and hydrology published since SEIS-I.

4.1.3.1 Geology

No substantive changes have occurred in the understanding of the site and regional geology since SEIS-I. A brief description of surface and subsurface geology and seismicity, both at the WIPP site and the region immediately surrounding the WIPP repository, is presented here. For detailed descriptions, see the references listed above.

Regional Setting and Surface Geology

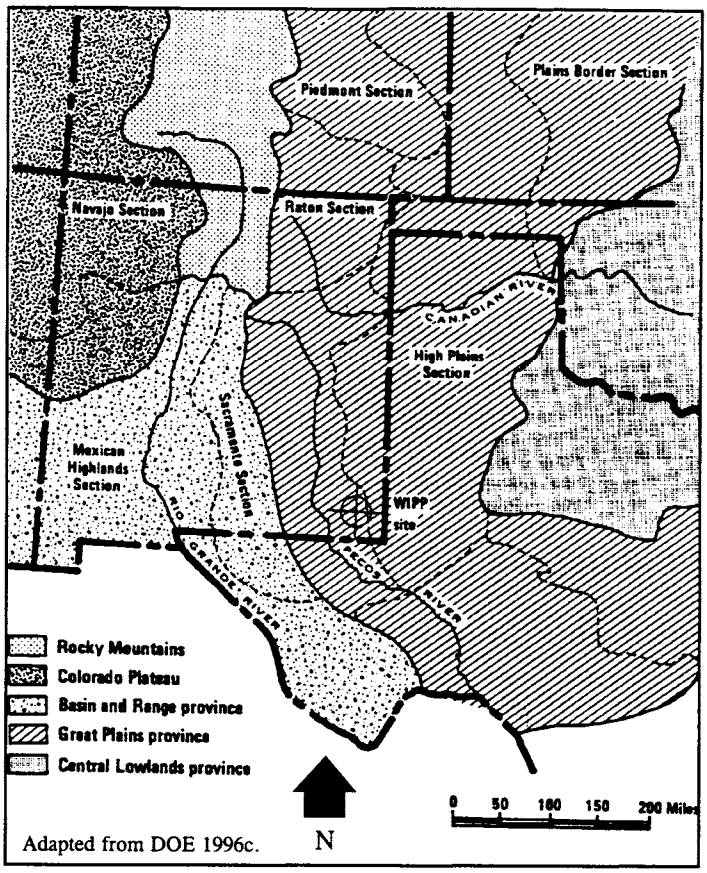
WIPP is located in southeastern New Mexico, in the Pecos Valley Section of the Great Plains Physiographic Province. The terrain throughout the province varies from plains and lowlands to rugged canyons. In the immediate vicinity of WIPP, numerous small mounds formed by wind-blown sand characterize the land surface. A layer enriched in calcium carbonate material, the Mescalero caliche, is typically present beneath the surface layer of sand. This caliche ranges in age from about 510,000 years at the base of the layer to about 410,000 years in the upper part, based on samples within the layer (DOE 1996c, Section 2.1). The caliche layer overlies a 600,000-year old volcanic ash layer (DOE 1996c, Section 2.1). The Mescalero caliche can be found over large portions of the Pecos River drainage area and is generally considered to be an indicator of surface stability (DOE 1980). The site slopes gently from east to west, from an elevation of 1,088 meters (3,570 feet) above sea level at its eastern boundary to 990 meters (3,250 feet) above sea level along its western boundary.

A high plains desert environment characterizes the area. Due to the seasonal nature of the rainfall, most surface drainage is intermittent. The Pecos River, 20 kilometers (12 miles) southwest of the WIPP boundary, is a perennial river and the master drainage for the region. A natural divide lies between the Pecos River and WIPP. As a result, the Pecos drainage system does not currently affect the site. Local physiographic features include Nash Draw and the San Simon Swale (see Figure 4-4).

Subsurface Geology

WIPP is located in the northern portion of the Delaware Basin, a structural basin underlying present-day southeastern New Mexico and western Texas and containing a thick sequence of sandstones, shales, carbonates, and evaporites. The references listed above describe basic characteristics of the stratigraphy (sequence of rock units) of the Delaware Basin.

The WIPP repository is located at a depth of approximately 655 meters (2,150 feet) in rocks of Permian age. The sediments accumulated during the Permian period represent the thickest portion of the sequence in the northern Delaware Basin and are divided into four series. From oldest to youngest, these series are: the Wolfcampian, Leonardian, Guadalupian, and Ochoan. As shown in Figure 4-5, the Ochoan series is divided into four formations. From oldest to youngest, these formations are: Castile, Salado (the lower part of which contains the WIPP repository), Rustler, and Dewey Lake.



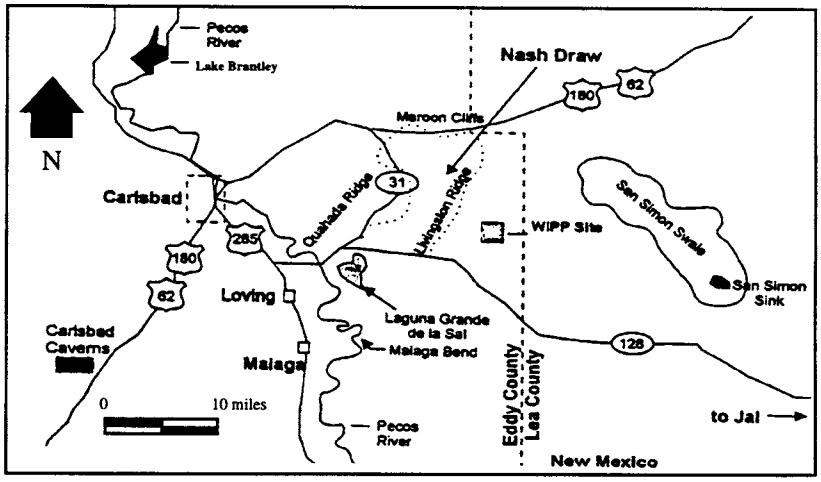


Figure 4-4
WIPP Site Location in Southeastern New Mexico

SYSTEM	SERIES	GROUP	FORMATION	MEMBER	DEPTH AT WIPP WASTE SHAFT meters (feet)
RECENT	RECENT		SURFICIAL DEPOSITS		
QUATERNARY	PLEISTOCENE		MESCALERO CALICHE		
			GATUNA		
TRIASSIC		DOCKUM	SANTA ROSA		30 (97)
PERMIAN	OCHOAN		DEWEY LAKE		164 (538)
			RUSTLER	Forty-niner	182 (596)
				Magenta Dolomite	189 (621)
				Tamarisk	215 (707)
				Culebra Dolomite	222 (729)
				lower unnamed	257 (844)
			SALADO	upper	409 (1,343)
				McNutt Potash	526 (1,727)
				lower WIPP	655 (2,150)
			CASTILE		~810 (2,650)
	GUADALUPIAN	DELAWARE MOUNTAIN	BELL CANYON		~1,200 (4,000)
			CHERRY CANYON		~1,550 (5,100)
			BRUSHY CANYON		~1,900 (6,200)

Figure 4-5
Regional Geologic Column

The discussion below presents the geologic formations important to understanding the long-term performance of WIPP, including: the host rock for the WIPP repository (the Salado Formation), the formations below the Salado (the Castile and Bell Canyon Formations), and the formations above the Salado (the Rustler and Dewey Lake Formations).

Salado Formation

The Salado Formation is a massive bedded salt formation, predominantly halite (sodium chloride), and is thick and laterally extensive. DOE selected the Salado Formation as the site of the WIPP repository for several geologic reasons (DOE 1980, 1990): (1) the Salado halite units have very low permeability to fluid flow, which impedes groundwater flow into and out of the repository; (2) the Salado is regionally widespread; (3) the Salado includes continuous halite beds without complicated structure; (4) the Salado is deep with little potential for dissolution; (5) the Salado is near enough to the surface that access is reasonable; and (6) the Salado is largely free of mobile groundwater, as compared to existing mines and other potential repository sites.

The Salado Formation is approximately 530 to 610 meters (1,740 to 2,000 feet) thick in the WIPP site area, and the repository is located in the thickest part. The Salado is comprised of three members. From oldest to youngest, these are: the Lower Member, the McNutt Potash Member, and the Upper Member. The WIPP repository is located in the Lower Member. The Salado contains many distinctive and laterally continuous layers composed mostly of anhydrite (a calcium sulfate mineral) and polyhalite (a potassium-magnesium-calcium sulfate mineral). These layers are so continuous that they have been used by geologists as "marker beds" (MB) and numbered to designate vertical position within the Salado Formation. The WIPP repository is located between MB 139 and MB 138.

Castile Formation

The Castile Formation directly underlies the Salado Formation and comprises the base of the Ochoan Series (see Figure 4-5). It is found 244 meters (800 feet) below the level of the repository. The Castile Formation near WIPP typically contains three relatively thick anhydrite/carbonate units and two thick halite units. The thickness of the Castile varies regionally as well as locally beneath WIPP, and there is considerable evidence from borehole data and geophysical surveys that the units of the Castile are deformed. The more brittle anhydrite units of the Castile are probably fractured, and the fracture zones are relatively permeable and act as zones for accumulation of brine originating in the Castile (DOE 1997a). The Castile is exposed at the surface over a considerable area along the western side of the Delaware Basin. In the eastern part of the basin, it is approximately 430 to 460 meters (1,400 to 1,500 feet) thick. At the northern boundary of WIPP, the Castile's thickness has been measured at 301 meters (989 feet).

Bell Canyon Formation

The Bell Canyon Formation underlies the Castile Formation and is the uppermost formation of the Guadalupian Series (see Figure 4-5). Near WIPP, the Bell Canyon is comprised of a layered sequence of sandstones, shales, siltstones, and limestones approximately 300 meters (1,000 feet) or more in thickness. It is the uppermost target of hydrocarbon exploration in the local area and is known from outcrops on the west side of the Delaware Basin and from oil and gas exploration boreholes (DOE 1996c, Section 2.1).

Rustler Formation

The Rustler Formation directly overlies the Salado Formation and contains five members (see Figure 4-5). From the base of the Rustler, these members are: the Unnamed lower member, the Culebra Dolomite, the Tamarisk, the Magenta Dolomite, and the Forty-niner. The Culebra and Magenta Dolomites are gypsum-bearing dolomites containing numerous cavities (vugs), fractures, and silty zones. The other three members contain various amounts of anhydrite, siltstone, claystone, and halite. The Rustler is the youngest (uppermost) formation in the Delaware Basin and primarily contains evaporite deposits. In the WIPP region, the Rustler can be 152 meters (500 feet) thick, although it ranges from 91 to 107 meters (300 to 350 feet) thick within the WIPP boundary.

Dewey Lake Formation

The Dewey Lake Formation overlies the Rustler Formation at WIPP (see Figure 4-5). Consisting largely of reddish-brown siltstones and claystones with lesser amounts of sandstone, the Dewey Lake Formation is about 30 to 170 meters (100 to 560 feet) thick in the vicinity of WIPP.

Santa Rosa Formation

The Santa Rosa Formation, also called the Dockum Group, overlies the Dewey Lake Formation. Characterized by light reddish-brown sandstones and conglomerates, the Santa Rosa Formation is thin to absent within the WIPP site boundaries, but is thicker (78 meters [255 feet] or greater) to the east (DOE 1996c, Section 2.1).

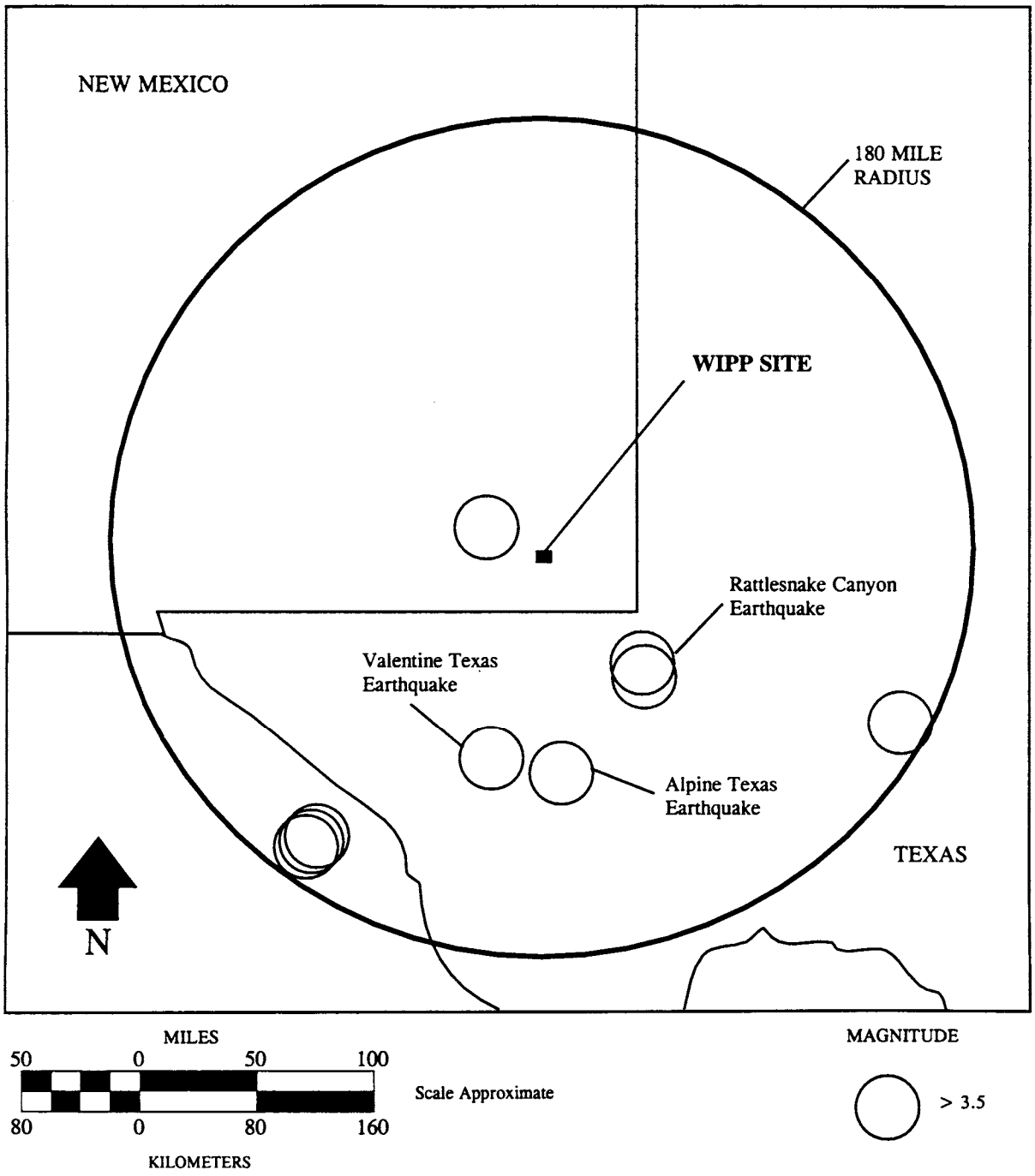
Gatuña Formation

The Gatuña Formation overlies the Santa Rosa Formation and is somewhat similar in lithology and color, although the Gatuña is characterized by a wide range of lithologies (coarse conglomerates to gypsum-bearing claystones). The Gatuña is Pleistocene in age, based on the 600,000-year old volcanic ash layer in the Upper Gatuña (DOE 1996c, Section 2.1). This is the same ash layer used to determine the upper age limit of the Mescalero Caliche that overlies the Gatuña Formation.

Faulting and Seismicity

Understanding of the regional seismicity has changed little since SEIS-I. No surface displacement or faulting younger than early Permian (Wolfcampian) has been reported, indicating that tectonic movement since then, if any, has not been noteworthy. No mapped Quaternary (last 1.9 million years) or Holocene (last 10,000 years) faults exist closer to the site than the western escarpment of the Guadalupe Mountains, about 100 kilometers (60 miles) west-southwest (DOE 1997a).

The strongest earthquake on record within 290 kilometers (180 miles) of the site was the Valentine, Texas, earthquake of August 16, 1931 (DOE 1997a), with an estimated Richter magnitude of 6.4. A Modified Mercalli Intensity V was estimated for this earthquake's groundshaking at WIPP. At Intensity V, groundshaking is felt by nearly everyone, a few instances of cracked plaster occur, and unstable objects are overturned. This is the strongest groundshaking intensity known for the WIPP site. This and other regional earthquakes are shown on Figure 4-6.



NOTES:

LOCATIONS OF SELECTED EARTHQUAKES WITHIN 300 KILOMETERS (180 MILES) OF THE WIPP SITE. FOR DRAFTING CLARITY NO EARTHQUAKE WITH A MAGNITUDE LESS THAN 3.5 IS SHOWN.

Figure 4-6
Regional Earthquake Epicenters Occurring after 1962

Since 1990, at least two seismic events have occurred that were recorded at WIPP. The Rattlesnake Canyon Earthquake occurred approximately 100 kilometers (60 miles) east-southeast of WIPP in January 1992. This event was assigned a Richter magnitude of 5.0 and occurred at a depth of approximately 12 kilometers (7.4 miles). This event had no effect on any of the structures at WIPP, as documented by post-event inspections by WIPP staff and the New Mexico Environment Department (DOE 1997a).

The most recent earthquake recorded at the WIPP site occurred on April 14, 1995, and was located 32 kilometers (20 miles) east-southeast of Alpine, Texas (approximately 240 kilometers [150 miles] south of the site). It was assigned a magnitude of 5.3 and is the largest event within 300 kilometers (185 miles) of the site since the Valentine, Texas, earthquake (Sanford et al. 1995). This event also had no effect on any structures at WIPP.

Based on a probabilistic seismic risk analysis and the region's historic seismicity, the strongest earthquake acceleration expected at WIPP would be 0.075 gravity (7.5 percent of acceleration due to gravity) with an average return period of 1,000 years. The design-basis earthquake (DBE) is conservatively assumed to be 0.1 gravity. Mine experience and studies on earthquake damage to underground facilities show that tunnels, mines, and wells are not damaged at sites having peak surface accelerations below 0.2 gravity (DOE 1997a).

Natural Resource Exploration and Development

Hydrocarbons

Prior to 1970, most commercially related drilling in the WIPP area targeted shallow oil (1,200 to 1,400 meters [4,000 to 4,500 feet] in depth) in the Bell Canyon Formation. Most of the exploratory wells from this period were plugged and abandoned. From 1970 to the mid-1980s, most drilling near WIPP focused on gas exploration in the deeper Morrow and Atoka Formations (approximately 4,000 meters [13,000 feet]). Most drilling for deep gas occurred northeast of WIPP. After parts of the Potash Area were opened to oil and gas exploration in the 1990s, exploration for deep gas in the Morrow and Atoka Formations occurred along the western boundary of the WIPP land withdrawal area (Broadhead et al. 1995).

According to Broadhead et al. (1995), estimates of probable oil and condensate resources within the WIPP Land Withdrawal Area include 12.3 million barrels of oil and gas condensate recoverable by primary production methods and an additional 6.4 million barrels of oil potentially recoverable by secondary recovery and waterfloods. Probable gas resources could total 5.3 billion cubic meters (186 billion cubic feet), 89 percent of which will be produced from the Atoka and Morrow Reservoirs. The remainder of the gas could be produced from shallow reservoirs in the Delaware Mountain Group. Probable resources within an additional 1.6-kilometer-wide (1-mile-wide) study area surrounding the withdrawn acreage include 22.9 million barrels of oil and gas condensate that could be recoverable by primary production methods and an additional 13.8 million barrels of oil that could be recoverable through waterflooding. Probable gas resources in this area could total 4.7 billion cubic meters (168 billion cubic feet), 79 percent of which could be produced from the deep Strawn, Atoka, and Morrow Reservoirs.

Broadhead et al. (1995) also state that possibly significant additional resources of oil, gas, and gas condensate exist beneath the WIPP site and the additional 1.6-kilometer-wide (1-mile-wide) area in untapped sandstones of the Delaware Mountain Group, in largely unexplored and unevaluated

sandstones and carbonates of the Bone Spring Formation, and in carbonate reservoirs in the Wolfcamp and Strawn Group. During the late 1980s and early 1990s, commercial oil was discovered in the Cherry Canyon and Brushy Canyon Formations of the Delaware Mountain Group adjacent to the eastern and northeastern boundary of WIPP, at a depth of approximately 2,100 to 2,400 meters (7,000 to 8,000 feet). These formations are currently the primary exploration and development targets in the Permian Basin, one of the most actively explored areas in the United States (Broadhead et al. 1995).

According to a study of comprehensive well records for nine townships around the WIPP site (Broadhead et al. 1995), 532 wells had been drilled in search of oil and gas by the end of 1993 (Figure 4-7). Few wells had been drilled in the area prior to 1960. Between 1960 and 1989, drilling activity increased but was sporadic and never exceeded 20 wells per year. Since 1990, however, drilling has increased markedly, with annual totals increasing to a maximum of 140 wells in 1993 (Figure 4-8). This increase has been partially attributable to the opening of previously restricted areas of the Potash Area to drilling. Most of these wells were drilled into the Brushy Canyon Formation of the Delaware Mountain Group.

Three commercial wells have been drilled for oil and gas within the boundaries of the WIPP Land Withdrawal Area (see Figure 4-7). Two vertical wells were drilled within the area during the 1970s; neither one became a producing well. A third well was drilled in 1982 from a location outside of the WIPP Land Withdrawal Area. The well was drilled at an angle underneath the area to intercept gas in the Atoka Formation and is currently commercially productive (Broadhead et al. 1995).

Potash

Bedded potash was discovered in Eddy County, New Mexico, in 1925. By 1944, New Mexico was the largest domestic potash producer, representing 85 percent of consumption. Development continued through the 1950s and 1960s, reversed in the 1970s and, for several reasons has declined since (Barker and Austin 1995).

The Carlsbad Potash District, located in southeastern New Mexico near the northeastern border of the Delaware Basin, contains the largest domestic potash reserves. Sylvinite, a mixture of sylvite and halite, is the typical potash ore mined in the Carlsbad Potash District. The only potash mines in the state are located in Eddy and Lea Counties within the soluble potash zone. The WIPP Land Withdrawal Area occupies approximately 41 square kilometers (16 square miles) on the southeastern edge of the Known Potash Leasing Area (or Potash Enclave, administered by BLM) (see Figure 4-9). During the last decade or so, commercial potash mining has continued and the mining front is much closer to the WIPP site, having approached the site boundary on the southwestern side. Future mining is likely to occur there or on the north side of the site (Barker and Austin 1995).

Within the Known Potash Leasing Area, the majority of actively mined and potential resources of potash ore are found in the 37-meter-thick (120-foot-thick) McNutt Member of the Salado Formation, which is the host for 11 ore zones. Horizon Number 1 is at the base of the McNutt Member and Number 11, which is not mined, is at the top. In the vicinity of the withdrawal area, the McNutt Member is found at depths ranging from 400 to 525 meters (1,312 to 1,722 feet) above the repository horizon. An additional ore zone is found in the Upper Member of the Salado.

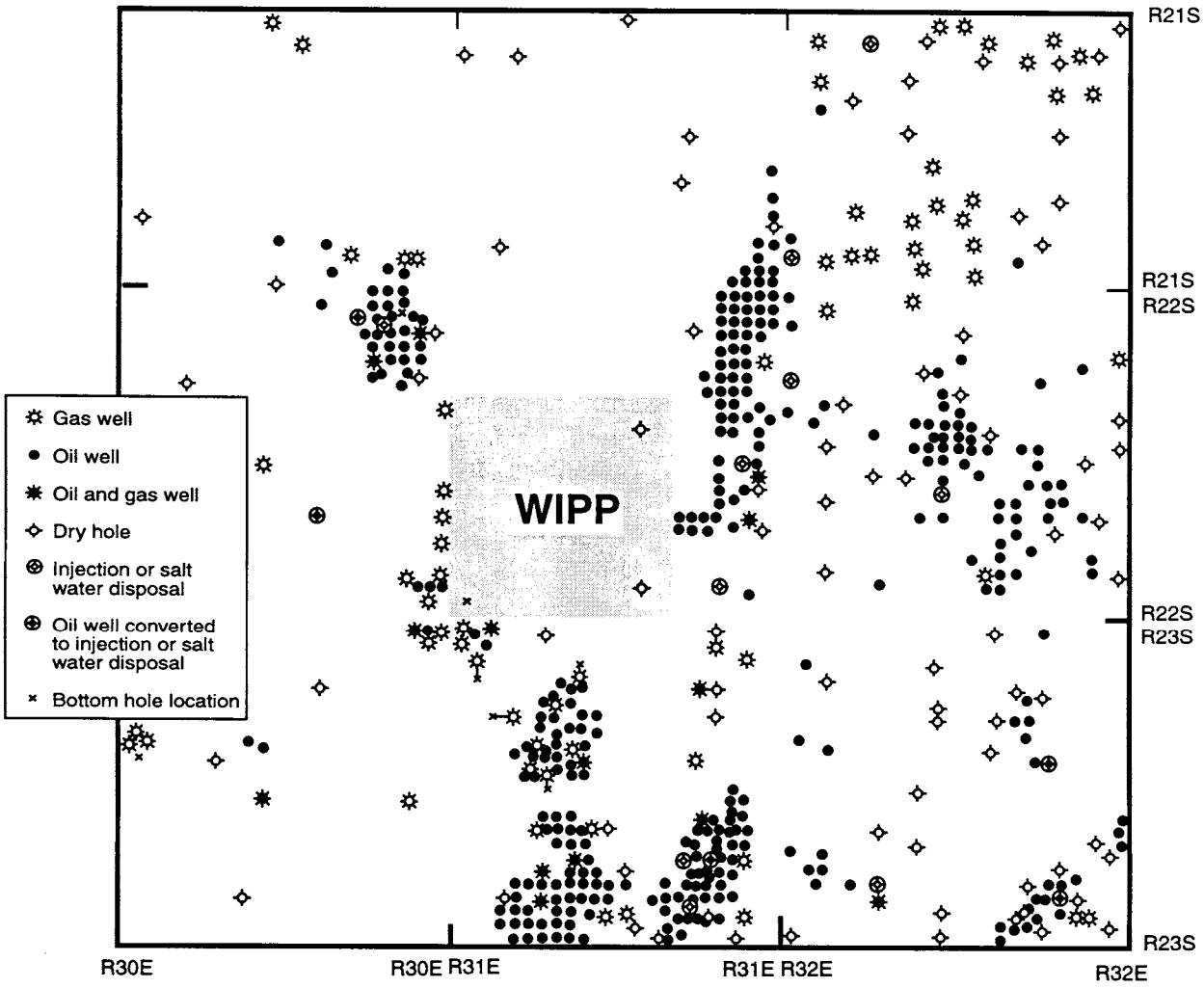


Figure 4-7
Oil, Gas, and Injection Wells in the Nine-Township Area Centered on the WIPP Site

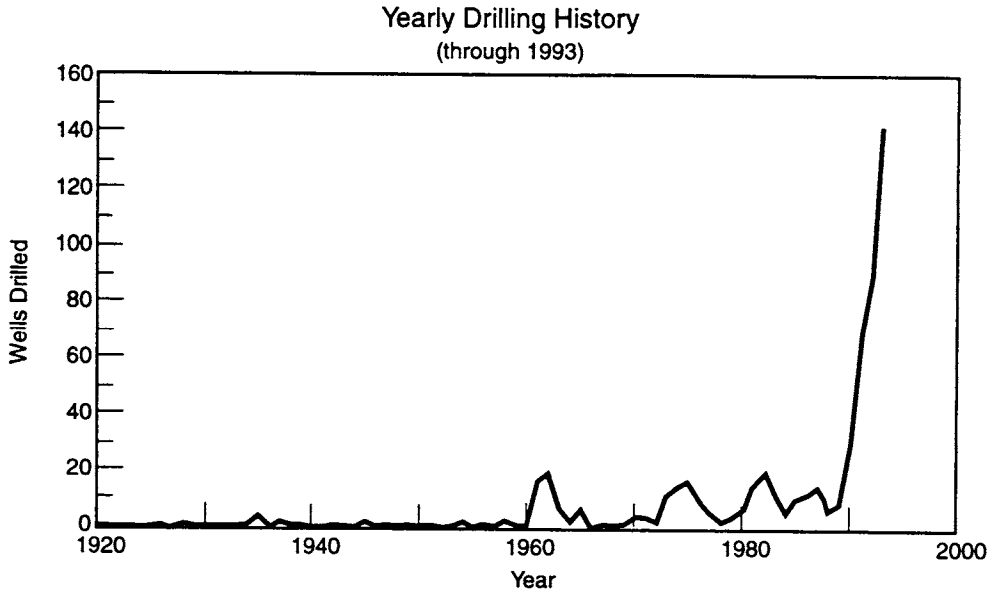


Figure 4-8
Annual Number of Oil and Gas Wells Completed in the Nine-Township Area Centered on the WIPP Site

Potash ore zones are 1 to 3 meters (3 to 10 feet) thick and are laterally consistent except where interrupted by salt horses, collapse features, and igneous dikes (Barker and Austin 1995). Continuous mining equipment that has been adapted from coal mining is used to extract most of the potash ore, although blasting is also used. All mines in the Carlsbad Potash District consist of at least two shafts for safety and ventilation, and older mines may have three or more shafts because working faces are now 5 to 8 kilometers (3 to 5 miles) from the main shafts.

A summary of the current knowledge and estimates of potash mining reserves, based on recent work performed by the New Mexico Bureau of Mines and Mineral Resources in the vicinity of the WIPP site, is provided in Attachment 15-5 of Appendix MASS of the *Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant* (CCA) (DOE 1996c). A summary of current leases indicates that all are held by eight holding companies, five of which are actively mining in the area. No active potash mining leases currently exist within the WIPP controlled area.

4.1.3.2 Hydrology

This section provides a summary of the surface hydrology of the WIPP region, followed by the hydraulic and hydrogeologic characteristics of the geologic formations relevant to WIPP.

Surface Water Hydrology

Understanding of the surface water hydrology in the WIPP vicinity has changed little since SEIS-I. WIPP is located east of the Pecos River and within the Pecos River basin (which represents about one-half of the drainage area of the Rio Grande Water Resources Region). The drainage area of

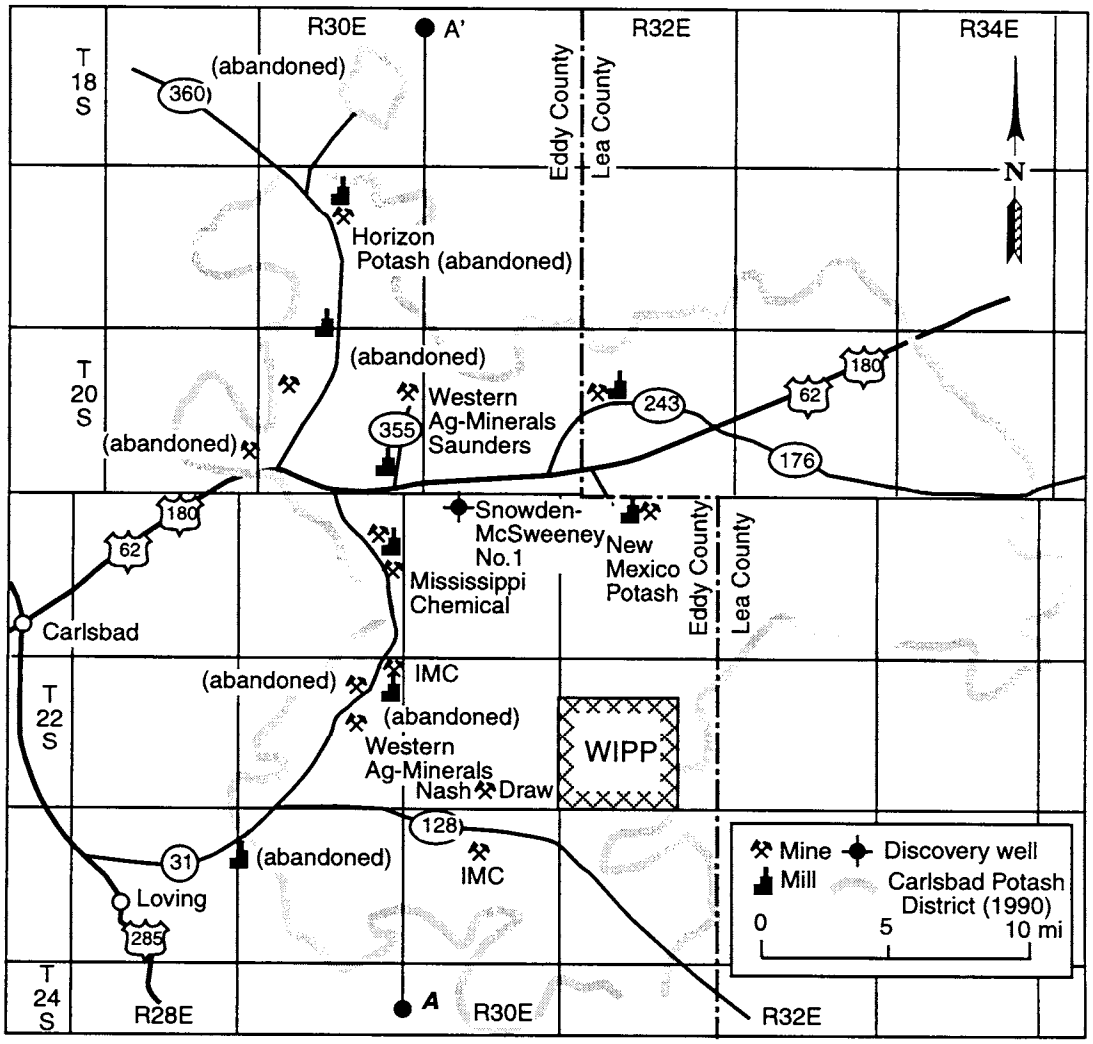


Figure 4-9
Active, Inactive, and Abandoned Potash Facilities in Eddy and Lea Counties, Southeastern New Mexico, Within the Carlsbad Potash District

the Pecos River at this location is 49,200 square kilometers (19,000 square miles). The WIPP site has a few small intermittent creeks, the only westward-flowing tributaries of the Pecos River within 32 kilometers (20 miles) north or south of the site.

The Pecos River is the main surface water resource in the WIPP vicinity. Due to inflow from brine springs (from the Rustler Formation) and slight exceedence of water quality levels of certain heavy metals (DOE 1996a), river water is not used for human consumption. Irrigation and livestock watering are the primary uses of the water from the Pecos.

More than 90 percent of the mean annual precipitation at the site is lost by evapotranspiration. On a mean monthly basis, evapotranspiration at the site greatly exceeds the available rainfall; however, intense local thunderstorms produce runoff and percolation. The maximum recorded flood on the Pecos River occurred on August 23, 1966, near Malaga, about 25 kilometers (15 miles) from WIPP. The maximum elevation of the flood was 90 meters (300 feet) below the elevation of the WIPP surface facility.

Groundwater Hydrology

The WIPP repository is situated in the thick, relatively impermeable Salado Formation salt beds 655 meters (2,150 feet) below the ground surface. The hydrologic and mechanical properties of the salt beds surrounding WIPP are better understood than the regional hydrology. Generally, however, groundwater in the Rustler and Dewey Lake Formations and the units overlying them are essentially isolated from the hydrology of the Salado Formation.

The Rustler Formation includes the Culebra and Magenta Dolomites, two units containing water of low quality (brine to brackish) (DOE 1996c, Section 2.2.1). The Culebra Dolomite, which is the first notable water-bearing unit above the Salado Formation, has been investigated for its potential to transport radionuclides released from the repository resulting from a borehole intrusion. Groundwater flow in the units overlying the Salado Formation has been assumed to occur primarily in the Culebra Dolomite, although it is recognized that regional flow in the Rustler Formation is three-dimensional and occurs to some degree in all Rustler units (DOE 1996c, Section 2.2.1). Flow in the Culebra is generally from north to south. The Dewey Lake Formation overlies the Rustler Formation and in some areas is relatively transmissive, particularly in the south central and southwestern part of the WIPP site (DOE 1996c, Section 2.2.1). The location of the water table is generally considered to be the Dewey Lake.

Only a few locations of groundwater recharge and discharge to and from the Rustler Formation are known. The only documented areas of naturally occurring groundwater discharge in the vicinity of WIPP are the Pecos River near Malaga Bend (Hunter 1985) and, to a lesser extent, the saline lakes in Nash Draw. This local flow associated with Nash Draw is unrelated to groundwater flow at WIPP. The only documented area of groundwater recharge is also near Malaga Bend (Hunter 1985). This location is hydraulically downgradient from the repository, and recharge here has little relevance to flow near WIPP. Recent regional groundwater modeling by Corbet and Knupp (1996) has suggested that groundwater in the Culebra, Magenta, and Dewey Lake and Triassic units originates in areas that are north and northeast of the WIPP site (DOE 1996c).

The following sections discuss the hydraulic and hydrogeologic characteristics of the geologic formations enclosing, underlying, and overlying the WIPP underground facility.

Salado Formation Hydrology

As described above, the Salado Formation has several characteristics which make it a favorable host medium for a repository, including its low permeability to fluids and its relatively low water content. Hydraulic tests from which permeabilities have been derived indicate that the Salado halite has either extremely low or no permeability (no measurable flow occurred during some of the tests). Tests in pure halite indicate permeabilities of less than 1×10^{-23} square meters (1×10^{-22} square feet); permeabilities measured in impure halite range from 1×10^{-23} to 4×10^{-18} square meters (1×10^{-22} to 4×10^{-17} square feet) (DOE 1996c, Section 2.2.1).

There is also indirect evidence of the Salado's low permeability. Measurements in the Salado in the WIPP site region have shown that there are areas of anomalously high and low fluid pressures. If the Salado were relatively permeable, these pressures would likely have equalized relatively quickly; conversely, if the Salado were relatively impermeable, these pressures would probably not equalize, or would do so only over a very long time. Since these pressure differences do exist, it is likely that these areas of anomalous pressures have remained constant over long periods of time because of the relative lack of permeability of the salt (Lappin et al. 1989).

Inflow of brine into the repository excavation has been observed in boreholes and from "weeps," which are localized brine seeps issuing from cracks in the disturbed surfaces of the repository walls, floors, and roofs. The volumes of brine observed from these occurrences have been small, and flow into the repository has ceased within three years of initial observation (DOE 1996c, Appendix MASS). Brine migrates along clay-rich layers and cracks developed in the "disturbed rock zone" (DRZ). Eventually the DRZ heals, thereby cutting off fracture-controlled flow paths into the repository. Nevertheless, for the long-term, it is reasonable and conservative to consider that there may be brine near the repository that would flow toward and into the repository, albeit at a low rate.

Models are available to estimate the amount of brine that would flow into the excavation over time. DOE (1996c) discussed three mechanisms of brine inflow: (1) far-field flow, which is flow from outside the influence of the repository along naturally interconnected pore spaces; (2) redistribution, which is flow within the interconnected fractures of the DRZ; and (3) clay consolidation, which is the squeezing of water out of clay layers which intersect the repository. Of these mechanisms, only the first two are considered crucial (DOE 1996c, Appendix MASS); together, they are capable of contributing approximately 50 to 160 cubic meters (1,785 to 5,712 cubic feet) of brine per disposal room, which has an approximate volume of 3,675 cubic meters (128,700 cubic feet) (DOE 1996c, Appendix MASS).

Brine inflow is a concern in that the brine would provide necessary moisture for the degradation of certain waste material components and gas generation. This could occur from a combination of processes such as microbial activity, canister corrosion, corrosion of metal waste, and radiolysis of brine. If a sufficient supply of brine exists and gas accumulates faster than it can dissipate, it is conceivable that gas pressure could build up to the point that it exceeds lithostatic pressure (approximately 15 million pascals). In this event, fractures would form in the repository walls and provide pathways for contaminants away from the repository.

According to the CCA (DOE 1996c), the total volume of gas that may be generated by corrosion and microbial degradation may be sufficient to result in repository pressures that approach

lithostatic levels. Sustained pressures above lithostatic levels are not physically reasonable within the disposal system, and fracturing of the more brittle anhydrite layers is expected to occur if sufficient gas is present. The permeability and porosity of the anhydrite marker beds (MB 138 and MB 139) will increase rapidly as pore pressure approaches and exceeds lithostatic levels. Pressure-dependent fracturing approximates the hydraulic effect of pressure-induced fracturing and will likely allow gas and brine to move more freely within the marker beds at higher pressures. The interbeds may be expected to serve as conduits for brine flow between the impure halite and the repository. Conceptually, brine flows laterally along higher permeability interbeds toward or away from the repository and vertically between the interbeds and the lower permeability halite. Because the interbeds have a very large contact area with adjacent halite-rich rock, even a very small flux from the halite into the interbeds (for brine inflow) or to the halite from the interbeds (for brine outflow) can accumulate into a significant quantity of brine. In this manner, halite serves as a source or sink for brine in the repository. It is expected that, because of density differences between gas and brine and their stratification within the repository, brine outflow will be dominantly in MB 139, and gas outflow will occur in anhydrite a and b or MB 138.

Interbeds also contain natural fractures that may be partially healed. If high pressure is developed in an interbed, its preexisting fractures may dilate or new fractures may form, altering its porosity and permeability. Pressure-dependent changes in permeability are supported by experiments conducted in the WIPP underground and in the laboratory (Beauheim et al. 1993). To the extent that it occurs, dilation or fracturing of interbeds is expected to increase the transmissivity of interbed intervals. The threshold pressure of dilated or fractured interbeds is expected to be low because apertures of the fractures increase; thus, fluid is expected to be able to flow outward readily if adequate pressure is available to dilate the interbeds.

The Salado salt has such a low permeability that it is difficult to measure with existing technology. Studies of the Salado indicate that the impure halite (greater than 0.5 percent impurities) may exhibit brine flow through pore spaces and along grain boundaries, but measurements on continuous layers of pure halite indicate zero or near-zero permeabilities. The interpretation of flow mechanism is inconclusive. The presence of the pure halite layers suggests that vertical flow through the Salado does not occur (DOE 1996c, Section 2.2.1).

Castile Formation Hydrology

The Castile Formation is dominated by anhydrite and halite zones of low permeability (DOE 1996c, Section 2.2.1.2); however, fracturing in the anhydrite zone of the upper portion of the Castile has generated isolated regions with much greater permeability than the surrounding intact anhydrite. These regions, referred to as brine reservoirs, contain brine at greater than hydrostatic pressure.

Castile brine reservoirs in the northern Delaware Basin contain widely spaced, highly-angled fractures; therefore, a borehole which penetrated through a brine reservoir would be unlikely to intersect a fracture and release brine. Appreciable volumes of brine have been produced from several reservoirs in the Delaware Basin, but there is little direct information on the areal extent of the reservoirs or the interconnection between them (DOE 1996c, Section 2.2.1.2).

Borehole ERDA-6, located 5 kilometers (3 miles) northeast of the WIPP site, and borehole WIPP-12, 1.6 kilometers (1 mile) north of the site center, encountered a zone of pressurized brine within the Castile Formation (DOE 1996c, Section 2.2.1.2). The fluid pressure measured in 1983

in the WIPP-12 borehole was 12.7 megapascals, greater than the nominal hydrostatic pressure of 11.1 megapascals for a column of equivalent brine at that depth. Results of hydraulic tests performed in the ERDA-6 and WIPP-12 boreholes suggest that the extent of the highly permeable portions of the Castile is limited. The vast majority of brine is thought to be stored in low-permeability microfractures, with about 5 percent of the overall brine volume stored in large, open fractures. The volumes of the ERDA-6 and WIPP-12 brine reservoirs were estimated in 1983 to be 100,000 cubic meters (3.5×10^6 cubic feet) and 2.7 million cubic meters (9.5×10^7 cubic feet), respectively.

A geophysical survey using time-domain electromagnetic (TDEM) methods was completed over the WIPP-12 brine reservoir and the waste disposal panels (DOE 1996c, Section 2.2.1.2). The TDEM measurements detected a conductor thought to be the WIPP-12 brine reservoir and also indicated that similar brine reservoirs may be present within the Castile under a portion of the waste disposal panels. In a recent geostatistical analysis, 354 drill holes and 27 Castile brine occurrences were used to establish that there is an 8 percent probability that a hole drilled into the waste panel region would encounter brine in the Castile. This analysis is included in the CCA as Attachment 18-6 in Appendix MASS (DOE 1996c).

The origin of brine in the Castile has been investigated geochemically and reported in the CCA in Section 2.1.6.2 (DOE 1996c). Based on the ratios of major and minor element concentrations in the brine, the report concluded that these fluids originated from ancient seawater and that no evidence exists for fluid contribution from present meteoric waters. The Castile brine chemistries from the ERDA-6 and WIPP-12 reservoirs are distinctly different from each other and from local groundwater samples. The geochemical data indicate that the brine in reservoirs has not mixed to any significant extent with other bodies of water and has not circulated. The brine is saturated, or nearly so, with respect to halite and, consequently, has little potential to dissolve halite.

Bell Canyon Formation Hydrology

The Bell Canyon Formation is considered to form a single hydrostratigraphic unit about 300 meters (1,000 feet) thick. The low-permeability of the Castile Formation that overlies it effectively isolates the fluid flow in the Bell Canyon. In the WIPP vicinity, the brines in the Bell Canyon flow northeasterly and discharge into the Capitan aquifer (DOE 1996c, Section 2.2.1.2).

Rustler Formation Hydrology

The Rustler Formation is the most significant hydrogeologic unit above WIPP because it contains the Culebra Dolomite, the first laterally continuous hydrologic unit above the Salado Formation. In addition to the Culebra, the Rustler Formation also contains four other units: 1) the Unnamed Lower Member, 2) the Tamarisk Member, 3) the Magenta Dolomite Member, and 4) the Forty-Niner Member. The following summary of the most current understanding of all these units draws mainly from discussions in the CCA (DOE 1996c, Section 2.2.1.4).

Unnamed Lower Member

The Unnamed Lower Member makes up a single hydrostratigraphic unit in WIPP models of the Rustler Formation, although its composition varies somewhat (DOE 1996c, Section 2.2.1.4). Overall, it acts as a confining layer: the basal interval of the Unnamed Lower Member, approximately 19.5 meters (64 feet) thick, is composed of siltstone, mudstone, and claystone, and

contains the water-producing zones of the lowermost Rustler. Transmissivity values of 2.9×10^{-10} square meters (3.12×10^{-9} square feet) per second and 2.4×10^{-10} square meters (2.58×10^{-9} square feet) per second were reported from tests at well H-16, corresponding to hydraulic conductivities of 1.5×10^{-11} meters (4.95×10^{-11} feet) per second and 1.2×10^{-11} meters (3.96×10^{-11} feet) per second. Hydraulic conductivity in the lower portion of the Unnamed Lower Member is believed by DOE to increase to the west in and near Nash Draw, where dissolution at the underlying Rustler-Salado contact has caused subsidence and fracturing of the sandstone and siltstone. The porosity of the Unnamed Lower Member was measured in 1995 as part of the H-19 hydropad testing. Two claystone samples had effective porosities of 26.8 and 27.3 percent, and one anhydrite sample had an effective porosity of 0.2 percent.

The remainder of the Unnamed Lower Member contains mudstones, anhydrite, and variable amounts of halite. The hydraulic conductivity of these lithologies is extremely low; tests of mudstones and claystones in the waste handling shaft gave hydraulic conductivity values varying from 6×10^{-15} meters (1.98×10^{-14} feet) per second to 1×10^{-13} meters (3.28×10^{-13} feet) per second (DOE 1996c, Section 2.2.1.4).

Culebra Member

The Culebra Member, also referred to as the Culebra Dolomite, has been the most investigated hydrogeologic unit in the Rustler Formation during the past decade since it is the most transmissive unit at the WIPP site. Because of its hydraulic characteristics, the Culebra is considered the most likely pathway for radionuclide releases from the repository to the accessible environment.

According to the CCA, Culebra flow patterns have been recognized as moving predominantly north to south on the WIPP site and strongly affected by a high transmissivity zone in the southeastern portion of the site. Contours of these water levels suggest that the flow above the WIPP repository is to the south, flow in Nash Draw is to the southwest, and flow south of WIPP is possibly toward the west.

In the past trends in water chemistry along the inferred southerly flow have been an issue in interpretations of local flow conditions in the Culebra Dolomite. Using generally accepted interpretations of flow and chemistry, total dissolved solids would be expected to decrease and the general character of groundwater would be expected to change in the principal direction of groundwater flow. A number of past interpretations of groundwater flow paths and solute chemistry of the Culebra were based on the concept that groundwater flow in the Culebra was a confined system and that rock interactions along the flow path from WIPP must transform the groundwater from a more saline sodium chloride-type water to a more dilute calcium sulfate-type water.

In a recent interpretation by Corbet (1997), the Department has suggested that changes in groundwater chemistry that would be expected for a confined system are complicated by contributions of vertical leakage and regional groundwater recharge that interact with distinctive rock types originating in different areas surrounding the WIPP site. Corbet (1997) concludes that the distributions of solute chemistry observed in the Culebra are consistent with inferred groundwater flow conditions and reflect with a mixing of distinctly different groundwater originating in recharge areas to the east (slowly moving saline groundwater originating from dissolution of the Rustler and/or Salado and moving to the west), southwest (groundwater reacting

with anhydrites of the Rustler and flowing southeast), and north and northeast (meteoric recharge water reacting with Rustler anhydrites and moving south through the WIPP site).

Over the years, both hydraulic and tracer tests have been used to characterize the flow and transport characteristics of the Culebra. The Culebra is a fractured dolomite layer with properties that vary horizontally and vertically. Examination of core and shaft exposures has revealed that there are multiple scales of porosity within the Culebra, including fractures ranging from microscale to potentially large, vuggy (cavity-filled) zones, and interparticle and intercystalline porosity. Measurements of core samples indicate porosities ranging from 0.03 to 0.30 (DOE 1996c, Section 2.2.1.4); this large range in porosity for small samples is expected, given the variety of porosity types within the Culebra. The core measurements indicate that the Culebra has a significant number of porosity connections leading to a limited amount of fluid movement, particularly within interparticle cavities where the porosity and permeability is high, such as in chalky lenses.

The majority of fluid movement in the Culebra occurs within fractures and within vugs connected by fractures (DOE 1996c, Section 2.2.1.4). In some regions, the permeability of the fractures is inferred to be significantly higher than the permeability of the other porosity types; in other regions, there appear to be no fractures of high permeability, which may be due to a lack of large fractures or the result of gypsum fillings in portions of the Culebra.

The hydraulic tests have been designed to yield pressure data that can be used in the interpretation of Culebra transmissivity, permeability, and storativity. The most detailed hydraulic data have been collected from tests at the WIPP hydropads, which generally comprise a network of three or more wells located within close proximity of each other. Long-term pumping tests yielding pressure data over a large area have been conducted at hydropads H-3, H-11, and H-19, and at well WIPP-13. In addition, slug tests and short-term pumping tests conducted at individual wells have provided pressure data that can be used to interpret the transmissivity at those locations. Detailed cross-hole hydraulic tests that yielded data on hydraulic properties have recently been conducted at the H-19 hydropad. The pressure data from long-term pumping tests and the interpreted transmissivity values for individual wells are used to generate the transmissivity fields of the Culebra that were used in performance assessment flow modeling (see DOE 1996c, Appendix TFIELD).

In order to evaluate the transport properties of the Culebra Dolomite, a series of tracer tests was conducted at the H-2, H-3, H-4, H-6, H-11, and H-19 hydropads near the WIPP site. Tests at the first five locations consisted of two-well dipole tests and/or multi-well convergent flow tests and are described in detail in Jones et al. (1992). More recent tracer tests at the H-19 hydropad and additional tracer tests performed at the H-11 hydropad consisted of single-well injection-withdrawal tests and multi-well convergent flow tests and are described in the CCA (DOE 1996c, Section 2.2.1.4). The recent tracer tests were specifically designed to evaluate the importance of horizontal and vertical heterogeneity and diffusion on transport processes.

Tamarisk Member

The Tamarisk Member functions as a confining layer. Attempts were made in two wells, H-14 and H-16, to test a 2.4-meter (7.9-foot) sequence of the Tamarisk that consists of layers of claystone, mudstone, and siltstone sandwiched between layers of anhydrite. The permeability was too low to measure in either well within the time allowed for testing; consequently, the transmissivity of the

claystone sequence was estimated to be less than approximately 2.7×10^{-11} square meters (2.9×10^{-10} square feet) per second, one or more orders of magnitude less than that of the tested interval in the Unnamed Lower Member. The porosity of the Tamarisk was measured in 1995 as part of testing at the H-19 hydropad. Two claystone samples had an effective porosity of 21.3 to 21.7 percent, and five anhydrite samples had effective porosities of 0.2 to 1.0 percent (DOE 1996c, Section 2.2.1.4).

Magenta Member

The Magenta Member is a conductive, hydrostratigraphic unit about 7.9 meters (26 feet) thick at WIPP. The Magenta is saturated except near outcrops along Nash Draw, and hydraulic data are available from 15 wells. Transmissivity ranges over five orders of magnitude from 1×10^{-9} to 4×10^{-4} square meters (1.08×10^{-8} to 4.30×10^{-3} square feet) per second. The porosity of the Magenta was measured in 1995 as part of testing at the H-19 hydropad. Four samples had effective porosities ranging from 2.7 to 25.2 percent (DOE 1996c, Appendix HYDRO).

The hydraulic transmissivities of the Magenta, based on sparse data, show a decrease in conductivity from west to east, with slight indentations of the contours north and south of WIPP that correspond to the topographic expression of Nash Draw. In most locations, the hydraulic conductivity of the Magenta is one to two orders of magnitude less than that of the Culebra. The Magenta does not have hydraulically significant fractures in the vicinity of WIPP. The hydraulic gradient across the site varies from 3 to 4 meters per kilometer (16 to 20 feet per mile) on the eastern side, steepening to about 6 meters per kilometer (32 feet per mile) along the western side near Nash Draw (DOE 1996c, Figure 2-32).

Inferences about vertical flow directions in the Magenta have been made from well data collected by DOE, which reported a downward flow out of the Magenta over the WIPP site, consistent with results of groundwater basin modeling. However, DOE concluded that flow between the Forty-Niner and Magenta would be upward in H-3, H-14, and H-16, three boreholes which yielded reliable pressure data for the Forty-Niner. This conclusion is not consistent with the results of groundwater modeling, and this inconsistency may be the result of local heterogeneity in rock properties that affect flow on a scale that cannot be duplicated in regional modeling. Like the Culebra, groundwater elevations in the Magenta have changed over the period of observation; in fact, the pattern of changes is similar to that observed for the Culebra and is attributed to the same causes (see Section 2.2.1.4 of the CCA, DOE 1996c).

Forty-Niner Member

The Forty-Niner Member is described as a confining hydrostratigraphic layer and consists of low-permeability anhydrite and siltstone about 20 meters (66 feet) thick throughout the WIPP area (DOE 1996c, Section 2.2.1.4). Tests reported in DOE (1996c) for H-14 and H-16 yielded transmissivities of about 3×10^{-8} to 8×10^{-8} square meters (3.23×10^{-7} to 8.61×10^{-7} square feet) per second and 3×10^{-9} to 6×10^{-9} square meters (3.23×10^{-8} to 6.46×10^{-8} square feet) per second, respectively. The porosity of the Forty-Niner was measured as part of the H-19 hydropad testing. Three claystone samples had effective porosities ranging from 9.1 to 24.0 percent, and four anhydrite samples had effective porosities ranging from 0.0 to 0.4 percent.

Rustler-Salado Contact Zone

The contact between the Rustler and Salado Formations in the vicinity of Nash Draw (see Figure 4-4) is of interest, because it provides evidence of earlier dissolution. It is an unstructured residuum of gypsum, clay, and sandstone created by the dissolution of halite and has been known as the brine aquifer or residuum. The residuum is absent under the WIPP site (DOE 1996c, Section 2.2.1.4).

Robinson and Lang (1938) suggested that the structural conditions that caused the development of Nash Draw might control the occurrence of the brine; thus, the brine aquifer boundary may coincide with the topographic surface expression of Nash Draw. Their studies show brine concentrated along a strip from 3.3 to 13 kilometers (2 to 8 miles) wide and about 43 kilometers (26 miles) long. Data from test holes indicate that the residuum containing the brine ranges in thickness from 3 to 18 meters (10.5 to 60 feet) and averages about 7 meters (24 feet).

Hydraulic properties for the area between Malaga Bend on the Pecos River and Laguna Grande de la Sal were estimated by Hale et al. (1954), who calculated a transmissivity value of 8.6×10^{-3} square meters (9.25×10^{-2} square feet) per second and estimated the potentiometric gradient to be 0.27 meter per kilometer (1.4 feet per mile). The coincident fluctuation of water levels in the area's test holes with pumping rates in irrigation wells along the Pecos River suggest the Rustler-Salado residuum to be part of a continuous hydrologic system.

In the northern half of Nash Draw, the approximate outline of the brine aquifer as described by Robinson and Lang (1938) has been supported by drilling associated with the WIPP hydrogeologic studies. These studies also indicate that the main differences in the aquifer's areal extent occur along the eastern side of Nash Draw where the boundary is very irregular and, in places (test holes P-14 and H-07), extends farther east than previously indicated. The recent studies also found a variability in thickness of residuum present in test holes WIPP-25 through WIPP-29, ranging from 3.3 meters (11 feet) in WIPP-25 to 33 meters (108 feet) in WIPP-29 in Nash Draw, as compared to 2.4 meters (8 feet) in test hole P-14 east of Nash Draw. The specific geohydrologic mechanism that has caused dissolution to be greater in one area than in another is not apparent, although a general increase in chloride concentration in water from the north to the south may indicate the effects of movement down the natural hydraulic gradient in Nash Draw.

The average hydraulic gradient within the residuum in Nash Draw is about 1.9 meters per kilometer (10 feet per mile). In contrast, the average gradient at the WIPP site is 7.4 meters per kilometer (39 feet per mile). This difference reflects the changes in transmissivity, which are as much as five orders of magnitude greater in Nash Draw. The transmissivity determined from aquifer tests in test holes completed in the Rustler-Salado contact residuum of Nash Draw ranges from 2.1×10^{-10} square meters (2.26×10^{-9} square feet) per second at WIPP-27 to 8.6×10^{-6} square meters (9.25×10^{-5} square feet) per second at WIPP-29. This is in contrast to the WIPP site proper, where transmissivities range from 3.2×10^{-11} square meters (3.44×10^{-10} square feet) per second at test holes P-18 and H-5c to 5.4×10^{-8} square meters (5.81×10^{-7} square feet) per second at test hole P-14 (DOE 1996c, Appendix HYDRO). Locations and estimated hydraulic heads of these wells are illustrated in the CCA (DOE 1996c, Figure 2-35).

Hale et al. (1954) believed the residuum discharges to the alluvium near Malaga Bend on the Pecos River. Because the confining beds in this area are probably fractured due to dissolution and

collapse of the evaporites, the brine (under artesian head) moves up through these fractures into the overlying alluvium and then discharges into the Pecos River.

Water in the Rustler-Salado contact residuum in Nash Draw contains the largest concentrations of dissolved solids in the WIPP area, ranging from 41,500 milligrams per liter (5.63 ounces per gallon) in borehole H-1 to 412,000 milligrams per liter (55.9 ounces per gallon) in borehole H-5c (DOE 1996c, Appendix HYDRO). These waters are classified as brines. The dissolved mineral constituents in the brine consist mostly of sulfates and chlorides of calcium, magnesium, sodium, and potassium; the major cations and anions are sodium and chloride. Concentrations of the other major ions vary according to the areal location of the sample, are probably directly related to the interaction of the brine and the host rocks, and reflect residence time within the rocks. Residence time of the brine depends upon the transmissivity of the rock, that is, the presence of large concentrations of potassium and magnesium in water is correlated with minimal permeability and a relatively undeveloped flow system.

Dewey Lake and the Santa Rosa Formation Hydrology

The Dewey Lake and Santa Rosa Formations and surficial soils overlie the Rustler Formation and are the uppermost hydrostratigraphic units considered by DOE (DOE 1996c). A brief description of the main features of these units is provided below.

Dewey Lake Formation

The Dewey Lake Formation, also referred to as the Dewey Lake Redbeds, contains a productive zone of saturation, probably under water table conditions, in the southwestern to south-central portion of the WIPP site and south of the site. Several wells operated by the J.C. Mills Ranch south of the WIPP site produce sufficient quantities of water from the Dewey Lake to supply livestock. Short-term production rates of 5.7 to 6.8 cubic meters (1,500 to 1,800 gallons) per hour were observed in boreholes P-9, WQSP-6, and WQSP-6a (DOE 1996c, Appendix USDW). The saturated zone is typically found in the middle of the Dewey Lake, 55 to 81 meters (180 to 265 feet) below the surface and appears to derive much of its transmissivity from open fractures. The saturated zone may be perched or simply underlain by less transmissive rock. Fractures below the saturated zone tend to be completely filled with gypsum. Open fractures and/or moist (but not fully saturated) conditions have been observed at similar depths north of the saturation zone, at the H-1, H-2, and H-3 boreholes (DOE 1996c, Appendix HYDRO).

DOE estimated the position of the water table in the southern half of the WIPP site from an analysis of drillers' logs from three potash exploration boreholes and five hydraulic test holes. Using log records of the elevation of the first moist cuttings recovered during drilling, the elevation of the water table over the WIPP waste panels was estimated to be about 980 meters (3,215 feet) above sea level. In comparison, the repository lies 385 meters (1,260 feet) above sea level.

Santa Rosa Formation

The Santa Rosa Formation is absent over the western portion of the WIPP site and crops out northeast of Nash Draw. It is present over the eastern half of the WIPP site, where it reaches a thickness of 91 meters (300 feet). Near the WIPP site, the Santa Rosa may have a saturated

thickness of limited extent. Its porosity is estimated at about 13 percent, and it has a specific capacity ranging from 0.029 to 0.041 liters per second per meter (2.3×10^{-3} to 3.3×10^{-3} gallons per second per foot) (DOE 1996c, Appendix HYDRO).

Potential Impacts of Karst and Dissolution Processes

The current understanding of the extent, timing, and features related to dissolution (including a brief history of past project studies related to karst) in the area surrounding WIPP is described in Section 2.1.6.2 of the CCA (DOE 1996c**)**. In summary, these studies and investigations show that the geomorphology of the region, particularly near Nash Draw and to a lesser extent near WIPP, has been influenced by shallow dissolution. Groundwater flow in the Culebra and other units of the Rustler is primarily controlled by fractures that have been affected by shallow dissolution processes. A significant proportion of the fractures within the Culebra are filled with secondary gypsum east of the WIPP; to the west of the site most fractures are open.

Groundwater basin modeling performed in the CCA suggests that the Culebra becomes progressively more confined toward the east, corresponding to an increase in the overburden towards the east. This is also thought to coincide with a decrease in the fracturing associated with dissolution at the Rustler-Salado boundary. Percolating groundwater has caused the lateral dissolution of halite at the top of the Salado, causing collapse of the overlying Rustler with consequent changes in hydrogeological properties. The most prominent lateral dissolution feature in the region is seen at Nash Draw, some 5 miles (8 kilometers) to the west of the WIPP site. Average rates calculated in previous investigations of karst indicate that dissolution at the top of the Salado at the edge of the WIPP site would not take place for some 225,000 years, and an additional 2 to 3 million years would be required for dissolution to reach the repository horizon.

Deep dissolution of salt or other evaporite minerals in formations near the WIPP site is distinguished from shallow and lateral dissolution not only by depth but also by the origin of the water. Groundwater originating from deep brine-bearing zones can lead to the formation of cavities at depths that could potentially cause the collapse of overlying beds. These processes could lead to the formation of collapse breccias if the overlying rocks are brittle or to deformation that causes fracturing if the overlying rocks are ductile. These pipes may reach the surface or pass upwards into fractures and then into cracks that do not extend to the surface. Breccia pipes may also form through the downward percolation of meteoric waters or accelerate contaminant transport from the repository by creating enhanced pathways of vertical flow that bypass low-permeability units in the Rustler. If dissolution occurred within or beneath the waste panels themselves, there could be increased circulation of groundwater through the waste and a breach of the Salado host rock.

Past investigations in the region have identified these types of deep dissolution features within the Delaware Basin; however, their occurrences have been limited to areas along the margins of the basin that are underlain by Capitan Reef. Because of these observations, deep dissolution is not expected to occur sufficiently close to WIPP nor to affect groundwater flow in the immediate region of WIPP during the period of regulatory concern.

Within Nash Draw, extensive fracturing of the Rustler allows more groundwater flow and, therefore, dissolution of the Rustler. East of Livingstone Ridge, there is less fracturing and dissolution in the Rustler. In the CCA, the Department has concluded that the extent of dissolution

at the top of the Salado will not reach the controlled area until long after 10,000 years. Thus, shallow and deep dissolution at the WIPP site were not considered in the CCA performance assessment calculations.

Potential Hydrologic Effects of Natural Resource Exploration and Development Activities

The wide range of natural resource-related activities, which historically have been and will continue to be important in the region, have implications for future site impacts. The following is a brief description of the potential impacts of hydrocarbon exploration and development and potash mining.

Potential Impacts from Oil and Gas Development

Just outside of the WIPP site, oil and gas reserves are accessed by drilling through the Salado Formation and into the underlying oil- and gas-bearing formations. In the early 1990s, the Delaware Basin in the vicinity of the WIPP site experienced a significant increase in oil and gas exploration and development (Broadhead et al. 1995). Current restrictions do not allow any drilling activities within the WIPP controlled area, therefore, no direct impact from drilling activities is expected.

Hydrocarbon exploration and development, as a normal part of operations, also involves the injection of brine into boreholes that are used for brine disposal and enhanced oil recovery. The production of oil and gas is often accompanied by the production of large volumes of reservoir brine. Typically, the unwanted brine is injected back into the subsurface in an approved zone or zones through the use of salt water disposal wells. As oil, gas, and reservoir brine are produced in primary oil production, the natural reservoir energy will be expended and secondary methods such as water flooding are used to enhance crude oil recovery. A successful water flooding operation injects pressurized water through a well borehole into the oil bearing zone, to force additional oil to flow towards the producing well. Without proper management, both primary and secondary recovery methods can have significant hydraulic impact on surrounding geologic media.

In 1988, sudden water level changes were observed in wells completed in the Culebra Dolomite south of the WIPP site. Changes were first observed in Well H-9, about 10 kilometers (6 miles) south of the WIPP site (Figure 4-10). From 1988 through mid-1993, water levels steadily rose almost 5.5 meters (18 feet) before dropping abruptly. Water levels continued to drop until the end of 1995; currently, water levels are on the rise.

Analysis of the water level changes in H-9 and a number of other observation wells in areas north and south of WIPP and in the vicinity of WIPP have suggested that the changes in wells to the south are the result of possible hydraulic impacts of water flooding activities south of the WIPP site. Although there is no direct evidence to conclude which water flooding operation or what specific hydraulic condition is creating the specific water level changes observed near the WIPP site, casing leaks are the most logical pathway for introduction of fluid into the Rustler Formation.

The problem of injected water migrating out of the zone also occurs at other oil fields underlying the Salado Formation in the region.

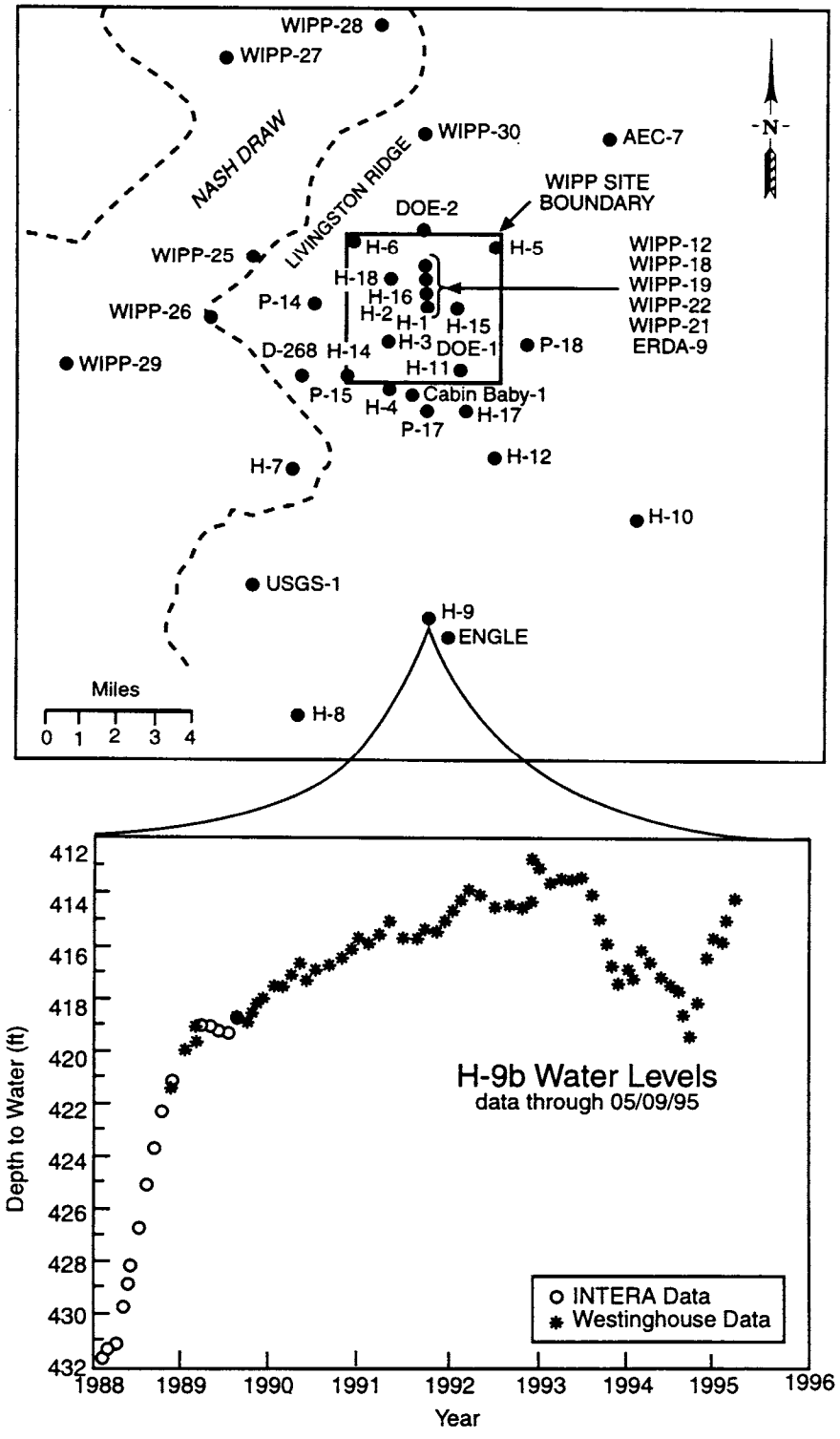


Figure 4-10
Locations of Wells Completed in the Culebra Dolomite in the Vicinity of the WIPP Site and Water-Level Changes in Observation Well H-9b between 1988 and 1996

Another example of potential hydrologic impacts from injection of large volumes of brine occurred in January, 1991 at a site located about 12 kilometers (8 miles) southeast of the WIPP site. In this incident, a borehole was in the process of being drilled through the Salado Formation when a salt water blowout, encountered at depths between 683 and 695 meters (2,240 and 2,280 feet), flowed uncontrollably for five days. In a lawsuit that followed, a claim was made that a nearby water flooding operation allowed large quantities of injected brine to escape out of an approved injection zone (which entered in the overlying Salado Formation) and migrate into the borehole. Evidence presented in the case substantiated the claim that brine injected to depths of about 915 meters (3,000 feet) had migrated out of the injection zone to the Salado Formation. The wells used in the water flooding operation were drilled and completed in the 1940s so the possibility of faulty well completion or failed well casing are potential causes of the out-of-injection zone migration. The potential for this type of incident to occur at WIPP was evaluated by DOE and was viewed as highly unlikely because of differences in geology between the WIPP site and the nearby site, changes in oil-well completion practices since the 1940s, and improved reservoir management practices.

The two examples of impacts noted above and other examples of the potential impacts of brine disposal and water flooding are described in more detail in Silva (1996).

Potential Impacts of Potash Mining

Potash mining has the potential to impact the hydrology of the area near the WIPP site in two ways. One impact involves the potential for mining operations and the development of room and pillar mines to cause weakening and collapse of overlying strata and subsequent subsidence. This may result in the propagation of fractures through both overlying water-bearing unit and potential contaminant pathways (e.g., the Culebra Dolomite), thereby increasing their hydraulic conductivity and potentially damaging petroleum well casings and uncased wells (Neill et al. 1996).

The other potential impact comes from the need of potash mining operations to dispose of brine generated during mining operations. As in the case of oil and gas drilling operations, potash mining requires the use of salt water disposal wells, and the potential exists that out-of-zone migration of brine injected through improperly sealed wells and deteriorating casing could have a potential impact on hydrologic conditions near the WIPP site.

Active and Passive Controls

The Department believes that planned active controls (see DOE 1996c, Chapter 7) will ensure that the prohibition on the drilling of hydrocarbon wells and on potash mining is enforced during the active institutional control period. For the purpose of this analysis, this period of active institutional control is assumed to be 100 years after the disposal operations period and site closure although it is the Department's intention to maintain active institutional control well beyond this period. Beyond the active institutional period, DOE intends to implement a set of passive institutional controls (DOE 1996c, Section 7.3.4) that are expected to significantly deter the possibility of human intrusion for 700 years. Beyond that time, the effectiveness of passive controls is expected to degrade, and the potential exists for drilling or mining activities to encroach into the area of the WIPP site, leading to an intrusion from one or more exploratory boreholes or from mines into the repository and/or underlying possible pressurized brine reservoir. This potential impact was evaluated in the long-term performance assessment analysis described in Chapter 5 and Appendix H.

4.1.4 Biological Resources

SEIS-I (DOE 1990) describes the WIPP site area as characterized by sand dunes. Further, it describes the vegetation as dominated by shinnery oak (*Quercus havardii*), mesquite *(Prosopis grandulosa*), sand sage (*Artemisia filifolia*), dune yucca (*Yucca campestris*), smallhead snakeweed (*Gutierrezia microcephala*), three-awn (*Aristida* spp.), and numerous species of forbs and perennial grasses. The most conspicuous mammals at the site are the black-tailed jack rabbit (*Lepus californicus*) and the desert cottontail (*Sylvilagus auduboni*); other common small mammals include Ord's kangaroo rat (*Dipodomys ordii*), plains pocket mouse (*Perognathus flavescens*), and northern grasshopper mouse (*Onychomys leucogaster*). Large mammals include mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), and coyote (*Canis latrans*). Loggerhead shrike (*Lanis ludovicianus*), Pyrrhuloxia (*Cardinalis sinuata*), and black-throated sparrow (*Amphispiza bilineata*) are common resident birds. The Harris hawk (*Parabuteo unicinctus*) is a resident raptor. Aquatic habitats near WIPP, which include stock watering ponds and tanks, may be frequented by yellow mud turtles (*Kinosternon flarescens*) and tiger salamanders (*Ambystoma tigrinum*) (DOE 1992, 1993b, 1994a, 1995d).

Since SEIS-I, ecological monitoring at WIPP has continued. Changes noted in vegetation distribution include an increase in shrub cover and a decrease in grasses such as black grama grass (*Bouteloua eriopoda)* near the salt tailings (due to the colonization of these habitats by salt-tolerant shrub species). No effects from salt-induced physiological stress were seen on the general vegetation of the area. Changes in cover and density during the last few years have been attributed to variations in annual rainfall (DOE 1993b, 1994a, and 1995d).

Wildlife monitoring has indicated increases in some species of birds at the site. This is primarily due to changes in surface conditions such as water availability (DOE 1992) and to increases in oilfield activities in areas surrounding the site which may have disturbed some populations and caused their relocation within the site (DOE 1994a). Surveys taken from 1984 through 1993 have documented 98 species of birds which inhabit or migrate through the area (DOE 1994a).

Mammal populations have fluctuated as a result of changes in natural conditions such as rainfall, temperature, and disease. No differences in mammal population numbers have occurred as a result of WIPP activities (DOE 1995d).

In consultation with the USFWS, the Department concluded in SEIS-I that the following threatened or endangered species occur or have the potential to occur on lands within or outlying the WIPP site: Lee's pincushion cactus (*Coryphantha sneedi* var. *leei*), American peregrine falcon, bald eagle (*Haliaeetus leucocephalus*), and Pecos gambusia (*Notropis simus pecosensis*). DOE stated that it believed the actions described in SEIS-I would have no impacts on any threatened or endangered species because those activities did

CHANGES IN RARE, THREATENED, AND ENDANGERED SPECIES

The threatened, endangered, and candidate species present in Eddy County, New Mexico, have changed since SEIS-I. In 1995, DOE consulted with the U.S. Fish and Wildlife Service (USFWS), the New Mexico Department of Game and Fish (NMDG&F), and the New Mexico Energy, Minerals and Natural Resources Department (NMEMNR) regarding the presence of federally threatened, endangered, and proposed species, state-listed rare and endangered animals, and state-listed rare and endangered plant species, respectively, in Eddy County, New Mexico. Since SEIS-I, more than 60 new state and federal species have been added to these county-wide lists, although no new species have been found at the WIPP site.

not involve any ground disturbance that was not already evaluated in the FEIS (DOE 1980). NMDG&F agreed with the Department that the anticipated WIPP activities would probably not have appreciable impacts on state-listed endangered species in the area. The Department concluded in SEIS-I that there is no critical habitat for terrestrial species identified as endangered by either the USFWS or the NMDG&F at the site (DOE 1990).

In September 1995, DOE contacted the USFWS to determine the occurrence of threatened, endangered, and proposed species at WIPP. The USFWS listed eight endangered, six threatened, and 37 proposed species for Eddy County, New Mexico (USFWS 1995) (see Table 4-1). At that time, DOE also contacted the NMDG&F and NMEMNR regarding the occurrence of state-listed rare, threatened, and endangered plant and animal species in Eddy County. The NMDG&F currently lists 22 threatened and 7 endangered animal species (NMDG&F 1995), and the NMEMNR lists 7 state-endangered and 17 state-sensitive plant species (Sivinski and Lightfoot 1995) (see Table 4-1). There is no designated critical habitat for such species at the WIPP site (NMDG&F 1995, USFWS 1995).

In 1996, DOE conducted another survey on the WIPP Land Withdrawal Area and associated lands to investigate the potential for impact to rare, threatened, endangered, or sensitive plant or animal species as a result of the potential actions presented in SEIS-II. The 1996 survey included an assessment of suitable habitats for these species. No threatened, endangered, or state-listed species were found on the WIPP Land Withdrawal Area during the survey. The data reported in the survey, which support the conclusions of other studies, suggest that dense and permanent populations of these species are not presently established on WIPP lands.

4.1.5 Cultural Resources

This section provides a brief evaluation of recent activities concerning the prehistoric and historic cultural resources at WIPP. FEIS (DOE 1980) summarized background discussions and data, followed by an update in SEIS-I (DOE 1990). More recent summaries of the WIPP cultural resources information are found in the *Waste Isolation Pilot Plant Land Management Plan* (DOE 1993a) and the *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1994* (DOE 1995d).

CHANGES IN CULTURAL RESOURCES MANAGEMENT

Memorandum of Understanding - In 1994, a memorandum of understanding between DOE and the Department of the Interior transferred management responsibility for cultural resources in the Land Withdrawal Area to DOE.

Cultural resources investigations at WIPP began in 1976 and have continued to the present. A review of the bibliography of existent WIPP cultural resources reports indicates that at least 24 separate investigations have been conducted. SEIS-I summarized two archeological investigations that provide further insight into the life of the hunter-gatherers who occupied the area of the WIPP site.

The first investigation excavated three sites that had been identified in FEIS that were in areas which could have been disturbed during construction activities. Two of the sites were plant-collecting and processing sites, and one was a base camp used between 1,000 B.C. and 1,400 A.D. The second investigation covered Control Zones III and IV and areas identified for

Table 4-1
Species of Special Concern in Eddy and Lea Counties, New Mexico [a]

Name	FE [b]	FT [c]	FC [d]	SE [e]	ST [f]	SR [g]
Mammals						
Arizona black-tailed prairie dog (*Cynomys ludovicianus arizonensis*)			X			
Big free-tailed bat (*Nyctinomops macrotis*)			X			
Black-footed ferret (*Mustela nigripes*)	X					
Cave myotis (*Myotis velifer*)			X			
Fringed myotis (*Myotis thysanodes*)			X			
Gray-footed chipmunk (*Tamias canipes*)			X			
Guadalupe southern pocket gopher (*Thomomys umbrinus guadalupensis*)			X			
Long-legged myotis (*Myotis volans*)			X			
Occult little brown bat (*Myotis lucifugus occultus*)			X			
Pale Townsend's big-eared bat (*Plecotus townsendii pallescens*)			X			
Pecos river muskrat (*Ondatra zibethicus ripensis*)			X			
Small-footed myotis (*Myotis ciliolabrum*)			X			
Swift fox (*Vulpes velox*)			X			
Yuma myotis (*Myotis yumanensis*)			X			
Birds						
American peregrine falcon (*Falco peregrinus anatum*)	X			X		
Arctic peregrine falcon (*Falco peregrinus tundrius*)		X				
Baird's sparrow (*Ammodramus bairdii*)			X		X	
Bald eagle (*Haliaeetus leucocephalus*)		X			X	
Bell's vireo (*Vireo bellii arizonae*)					X	
Black tern (*Chlidonias niger*)			X			
Broad-billed hummingbird (*Cynanthus latirostris*)					X	
Brown pelican (*Pelecanus occidentalis*)	X			X		
Common ground-dove (*Columbina passerina*)				X		
Ferruginous hawk (*Buteo regalis*)			X			
Gray vireo (*Vireo vicinior*)					X	
Interior least tern (*Sterna antillarum*)	X			X		
Loggerhead shrike (*Lanius ludovicianus*)			X			
Mexican spotted owl (*Strix occidentalis lucida*)		X				
Neotropical cormorant (*Phalacrocorax brasilianus*)					X	
Northern aplomado falcon (*Falco femoralis septentrionalis*)	X			X		
Northern goshawk (*Accipiter gentilis*)			X			
Southwestern willow flycatcher (*Empidonax traillii extimus*)	X				X	
Varied bunting (*Passerina versicolor*)					X	
Western burrowing owl (*Athene cunicularia hypugea*)			X			
White-faced ibis (*Plegadis chihi*)			X			
Reptiles						
Arid land ribbon snake (*Thamnophis proximus*)					X	
Blotched water snake (*Nerodia erythrogaster*)					X	
Dunes sagebrush lizard (*Sceloporus arenicolus*)			X		X	
Mottled rock rattlesnake (*Crotalus lepidus lepidus*)					X	
Texas horned lizard (*Phrynosoma cornutum*)			X			
Western river cooter (*Pseudemys gorzugi*)					X	

[a] Includes federal-endangered, -threatened, and -candidate species, state-endangered and -threatened species, and state-rare and -sensitive species. None of these species have been found during surveys at the WIPP sites. Due to revisions in the lists of endangered and threatened species, only two of the identified federal candidate species (the swift fox and Pecos pupfish) are still listed.

[b] FE = federal-endangered species (USFWS 1995)

[c] FT = federal-threatened species (USFWS 1995)

[d] FC = federal-candidate species (USFWS 1995)

[e] SE = state-endangered species (NMDG&F 1995, Sivinski and Lightfoot 1995)

[f] ST = state-threatened species (NMDG&F 1995)

[g] SR = state-rare and -sensitive species (Sivinski and Lightfoot 1995)

Table 4-1
Species of Special Concern in Eddy and Lea Counties, New Mexico — Continued [a]

Name	FE [b]	FT [c]	FC [d]	SE [e]	ST [f]	SR [g]
Fish						
Bigscale logperch (*Percina macrolepida*)					X	
Blue sucker (*Cycleptus elongatus*)			X	X		
Gray redhorse (*Moxostoma congestum*)					X	
Greenthroat darter (*Etheostoma lepidum*)					X	
Headwater catfish (*Ictalurus lupus*)			X			
Mexican tetra (*Astyanax mexicanus*)					X	
Pecos bluntnose shiner (*Notropis simus pecosensis*)		X			X	
Pecos gambusia (*Gambusia nobilis*)	X				X	
Pecos pupfish (*Cyprinodon pecosensis)*			X		X	
Plains minnow (*Hybognathus placitus*)			X			
Rio Grande shiner (*Notropis jemezanus*)			X			
Invertebrates						
Ovate vertigo (*Vertigo ovata*)			X		X	
Pecos springsnail (*Fontelicella pecosensis*)			X		X	
Texas hornshell (*Popenaias popei*)			X	X		
Plants						
Catchfly gentian (*Eustoma exaltatum*)						X
Chapline's columbine (*Aquilegia chrysantha chaplinei*)						X
Desert parsley (*Pseudocymopterus longiradiatus*)						X
Dune unicorn plant (*Proboscidea sabulosa*)						X
Few-flowered jewelflower (*Streptanthus sparsifloras*)			X			X
Gray sibara (*Sibara grisea*)						X
Guadalupe cliff daisy (*Chaetopappa hersheyi*)			X			X
Guadalupe mescal bean (*Sophora gypsophila guadalupensis*)						X
Guadalupe milkwort (*Polygala rimulicola rimulicola*)						X
Guadalupe penstemon (*Penstemon cardinalis regalis*)						X
Guadalupe rabbitbrush (*Chrysothamnus nauseosus texemsis*)			X			X
Guadalupe smooth aster (*Aster laevis guadalupensis*)			X			
Gypsum milkvetch (*Astragalus gypsodes*)						X
Gypsum wild buckwheat (*Erigonum gypsophilum*)		X		X		
Hitchcock's mockorange (*Philadelphus hitchcockianus*)						X
Kuenzler's hedgehog cactus (*Echinocereus fendleri kuenzleri*)				X		
Lee's pincushion cactus (*Coryphantha sneedii leei*)		X		X		
Lloyd's hedgehog cactus (*Echinocereus lloydii*)	X			X		
McKittrick pennyroyal (*Hedeoma apiculata*)						X
Scheer's pincushion cactus (*Coryphantha scheeri scheeri*)				X		
Shining coral root (*Hexalectris nitida*)			X	X		
Texas tobacco root (*Valeriana texana*)						X
Tharp's bluestar (*Amsonia tharpii*)			X	X		
Waterfall milkvetch (*Astragalus waterfallii*)						X
Wright's water-willow (*Justicia wrightii*)			X			X

[a] Includes federal-endangered, -threatened, and -candidate species, state-endangered and -threatened species, and state-rare and -sensitive species. None of these species have been found during surveys at the WIPP sites. Due to revisions in the lists of endangered and threatened species, only two of the identified federal candidate species (the swift fox and Pecos pupfish) are still listed.

[b] FE = federal-endangered species (USFWS 1995)

[c] FT = federal-threatened species (USFWS 1995)

[d] FC = federal-candidate species (USFWS 1995)

[e] SE = state-endangered species (NMDG&F 1995, Sivinski and Lightfoot 1995)

[f] ST = state-threatened species (NMDG&F 1995)

[g] SR = state-rare and -sensitive species (Sivinski and Lightfoot 1995)

possible land exchange. Sites encountered in the second investigation tended to lack evident or intact features. No definitive structures were identified. Of the 40 new sites identified, 14 were considered eligible for inclusion in the National Register of Historic Places (NRHP). The sites that are eligible or potentially eligible for the NRHP were mapped, and DOE activities have avoided disturbance of these sites. As a result of this past work, about 37 percent of the WIPP withdrawal area (1,551 hectares [3,830 acres]) has been inventoried for cultural resources.

To date, 60 archeological sites have been recorded in the withdrawal area, including 91 isolated occurrences (single or few artifacts, or isolated features). Sites and isolates are almost exclusively prehistoric in origin, and only one site with both prehistoric and historic components has been recorded. Based on the inventory data, and assuming environmental homogeneity and a fairly even distribution of archeological sites, DOE estimates that the WIPP site may contain about 99 archeological sites and 153 locations where isolated artifacts may be found (1993a).

There are no known Native American sacred sites or burials in the Land Withdrawal Area. Prior to the passage of the LWA in 1992, BLM managed the cultural resources on WIPP. In 1994, a memorandum of understanding between DOE and the Department of the Interior transferred management responsibility for cultural resources to DOE. Cultural resources are currently managed according to guidelines set forth in the WIPP Land Management Plan (DOE 1993a). DOE and the State of New Mexico have signed a Joint Powers Agreement that includes provisions specifying how DOE will satisfy its obligations regarding cultural resources under Sections 106 and 110 of the National Historic Preservation Act.

4.1.6 Socioeconomic Environment

The socioeconomic ROI for WIPP, as defined in FEIS (DOE 1980) and SEIS-I (DOE 1990), is Eddy and Lea counties in southeast New Mexico.[1] Any major changes in future activities undertaken at the WIPP site would have their most immediate socioeconomic effects in the two-county ROI. Principal centers of economic activity in the ROI include Artesia, Carlsbad, Hobbs, and Lovington. The oil and gas extraction and refining industries anchor the economies in both Eddy and Lea counties. Oil and gas mining services, mineral mining, tourism, and business services are the other significant industries of the ROI. The Carlsbad area also is known as a gateway to the Carlsbad Caverns-Guadalupe Mountains National Park complex. Economic impacts associated with WIPP primarily affect the Carlsbad portion of the ROI. Very few WIPP-related expenditures occur outside of the Carlsbad area, and very few direct WIPP employees reside elsewhere within the ROI. Most of the income spent by WIPP employees for local goods and services is spent in the Carlsbad area.

CHANGES IN SOCIOECONOMICS

Since publication in 1990 of SEIS-I, the following changes have occurred:

- *Census Information* - Demographic characteristics in SEIS-II are based on 1990 U.S. Bureau of the Census information as well as more recent data.
- *Economic Characteristics* - SEIS-II uses economic characteristics involving employment and wages covered by unemployment insurance from 1980 through 1990, based on 1994 information provided by the New Mexico Department of Labor and the University of New Mexico Bureau of Business and Economic Research.

[1] Towns in this ROI include Artesia, Atoka, Black River village, Carlsbad, El Paso Gap, Hope, Lakewood, Loco Hills, Loving, Malaga, Riverside, Seven Rivers, and Whites City in Eddy County. It also includes Caprock, Crossroads, Eunice, Hillburn City, Hobbs, Humble City, Jal, Lovington, Maljamar, McDonald, Monument, Nadine, Oil Center, and Tatum in Lea County.

Previous analyses of the socioeconomic impacts of WIPP on southeastern New Mexico occurred in Fiscal Year (FY) 1982 (Adcock et al. 1983), FY 1987 (Lansford et al. 1988), and most recently FY 1988 (Adcock et al. 1989). Socioeconomic analyses were also conducted for SEIS-I (DOE 1990). Employment and wage characteristics for 1994 are based on information provided by the New Mexico Department of Labor (NMDOL 1995) and the Bureau of Business and Economic Research of the University of New Mexico (BBER 1995). Other social and demographic characteristics reported for 1990 are based on 1990 Census information and more recent data compiled by the U.S. Bureau of the Census (1994). Lansford et al. (1994, 1995, 1996) also provide summary economic data relating to WIPP.

4.1.6.1 Background Characteristics

The construction of WIPP had some notable socioeconomic impacts in the ROI from 1981 through 1986. Subsequently, WIPP has had a relatively smaller impact on the socioeconomic characteristics in the ROI relative to changes from the extraction of oil and natural gas, the major industry of Eddy and Lea counties. This industry experienced a loss of almost one-third of its 1980 work force over the decade, substantially dampening the population growth in the ROI (BBER 1995). Correspondingly, WIPP-related activities tended to have a stabilizing effect on the local economy, particularly in Eddy County.

Table 4-2 shows that in 1990, four years after the major WIPP construction effort, the total population in the ROI was 104,370. This population is comprised of approximately 81.9 percent White, 32.4 percent Hispanic (both White and non-White), and 0.5 percent Native American. The ROI has smaller portions of Hispanic and Native American populations when compared to New Mexico as a whole, where the two groups comprise 38.2 percent and 8.9 percent, respectively. About 56 percent of the total ROI population is between the ages of 18 and 65. Overall, 65.4 percent of the ROI population has completed high school, with 11.2 percent attaining a baccalaureate degree or higher.

The ROI experienced slight advances in personal income in spite of the general downturn in oil and natural gas extraction during the 1980s. The median household and per capita income levels shown in Table 4-3 for the ROI were $23,305 and $10,241, respectively. Table 4-3 also shows that 17.4 percent of all families in the ROI were below the national poverty threshold. Poverty thresholds vary by family size and number of related children under 18 years of age. For example, the U.S. Bureau of the Census (1994) defined the national poverty threshold for a family of five persons in 1989 to be $14,900. New additions to the housing stock during 1990 through 1992 were relatively small across the ROI, while vacancy rates for rental units suggested ample availability of rental housing for under $350 per month.

4.1.6.2 Role of WIPP in the Economic Base

Table 4-4 lists recent information on local employment and wage earnings for the ROI. During 1994, a total of 38,094 employees earned $858 million in covered wages (wages covered by unemployment insurance) (NMDOL 1995). The most influential economic sectors in the ROI involved the extractive industries, the trade and service sectors, and government activities.

Given the stability of WIPP funding over the 1990s, the economic base of the ROI has been relatively less sensitive to changes in WIPP activities than to other large-scale enterprises such as the oil and gas industry. Declines in that industry in the 1980s resulted in lower employment and

Table 4-2
1990 Population and Community Characteristics by County in ROI [a]

Characteristic	Eddy	Lea	ROI Total [b]
Total population	48,605	55,765	104,370
Population by Race and Ethnicity			
White (percent)	81.5	82.2	81.9
Black (percent)	1.7	4.7	3.3
Native American (percent)	0.5	0.6	0.5
Asian (percent)	0.4	0.4	0.4
Other or Non-Reporting (percent)	15.9	12.1	13.9
Hispanic [c] (percent)	35.3	29.8	32.4
Population by Age and Education			
Percentage under 18	30.2	33.2	31.8
Percentage 65 and over	15.2	10.6	12.7
Percentage high school	67.3	63.8	65.4
Percentage bachelor degree	10.9	11.5	11.2
Total School Enrollment	13,489	16,457	29,946
College	2,010	2,765	4,775
Elementary or high schools	10,790	12,859	23,649
Community hospitals	2	2	4
Number of beds	156	278	434
Number of physicians	54	40	94

[a] ROI as defined for the socioeconomic environment constitutes a two-county aggregation based on 1990 census information.
[b] ROI percent totals are calculated on the total class level divided by the total ROI population.
[c] Hispanic is an ethnic characterization and consequently persons of Hispanic origin can be of any race.

Source: U.S. Bureau of the Census 1994.

Table 4-3
Income, Poverty, and Housing Characteristics (1989-1992) by County in ROI

Characteristic	Eddy	Lea	ROI Total
Median household income (dollars)	23,418	23,352	23,305
Per capita income (dollars)	10,490	10,025	10,241
Families below poverty line	2,162	2,806	4,968
Percentage of families below poverty line	16.2	18.5	17.4
Persons below poverty line	9,755	12,309	22,064
Percentage of persons below poverty line	20.4	22.4	21.1
Total housing units	20,134	23,333	43,467
Median value of owner-occupied units (dollars)	44,800	39,600	42,200
Median gross rent (dollars)	304	312	308
Vacancy rate	13.2	17.3	15.41
New building permits (1990-1992) as percentage of 1990 housing stock	< 1	< 1	< 1

Source: U.S. Bureau of the Census 1994.

Table 4-4
1994 ROI County Employment and Covered Wages (in Millions of 1994 Dollars)

Sector	Eddy		Lea		ROI Total	
	Employees	**Wage**	**Employees**	**Wage**	**Employees**	**Wage**
Agriculture	513	6.9	232	3.0	745	9.9
Mining	2,985	103.1	4,297	132.4	7,282	235.5
Construction	1,006	19.0	1,188	24.6	2,194	43.6
Manufacturing	921	31.0	529	9.8	1,450	40.8
Transportation and Utilities	1,628	52.2	1,487	51.7	3,115	103.9
Trade	3,798	51.4	4,891	77.9	8,689	129.3
F.I.R.E. [a]	614	13.7	529	12.1	1,143	25.8
Services [b]	3,753	62.9	3,668	65.9	7,421	128.8
Government						
Federal	425	15.7	123	4.2	548	19.9
State	420	8.9	238	5.6	658	14.5
Local	2,162	49.2	2,687	56.8	4,849	106
Totals	18,225	414	19,869	444	38,094	858
Unemployed percent	6.8		5.5		6.1	

[a] Finance, Insurance, and Real Estate

[b] The New Mexico Department of Labor classifies WIPP employees under the service sector industry, SIC 87.

Source: NMDOL 1995 and U.S. Bureau of the Census 1994.

wage earnings, while upturns in the 1990s have resulted in higher employment and wage earnings. Future growth and diversification of the economic base in the ROI would tend to diminish the economic impact of future changes in WIPP activities. WIPP, however, continues to play a role in the economic diversification of the Carlsbad economy, and several private ventures related to WIPP science and technology have started operations in Carlsbad. Depending on the extent to which they are reliant on the WIPP budget for their revenue, such businesses will be directly affected by alternatives considered in SEIS-II. Therefore, the more independent of WIPP these businesses become, the less they will be affected by federal actions at WIPP.

The direct economic impact of the anticipated WIPP operations reflects the levels of wage and salary payments to WIPP employees and the size of business and government procurement associated with WIPP construction and operations activities. At the time of the FY 1988 study, $24.3 million was paid in direct WIPP wages and salaries to 661 site personnel, while nonsalary expenditures were estimated to be $95.3 million (Adcock et al. 1989). By 1994, WIPP-related employment and annual wages had risen to 1,005 jobs and $44.56 million, respectively. This accounted for 2.6 percent of the total employment and approximately 5.2 percent of covered wage earnings in Eddy and Lea counties in 1994 (Landsford et al. 1995). In 1995, WIPP-related employment and covered wages dropped slightly to 952 jobs and annual wages of approximately $43.48 million (Landsford et al. 1996).

Nonsalary expenditures are mainly for regional support services, materials, capital equipment, and construction. However, WIPP outlays are also used to pay for business and government expenditures, including grants, community assistance, and out of region expenditures made through or by the local WIPP project office (DOE 1990).

The indirect economic impact of the anticipated WIPP operations is reflected by the subsequent spending and creation of new jobs that follow initial WIPP outlays in any given year. To assess the economic impacts of changes in the funding at the WIPP site, Adcock et al. (1989) estimated an economic activity multiplier value of 2.19 for FY 1988. That is, for every $1.00 spent by WIPP on materials, labor, benefits, equipment and services, another $1.19 worth of goods and services was generated in the ROI for a total impact of $2.19.

Relative to the $24.3 million of direct salaries and wages paid in FY 1988, an estimated additional $26.2 million of indirect wages and salaries were paid in the ROI in FY 1988 in support of 1,153 indirect jobs (Lansford et al. 1988). Meanwhile, the direct nonsalary expenditures of $95.3 million were estimated to generate an additional $113.6 million of indirect nonsalary expenditures in the local economy.

4.1.6.3 Environmental Justice

Environmental justice in the context of this document refers specifically to the potential for minority and low-income populations to bear a disproportionate share of high and adverse environmental impacts from activities at WIPP under the various SEIS-II alternatives. The environmental justice ROI covers all populations within an 80-kilometer (50-mile) radius of the reservation boundary of WIPP.[1] This region includes parts of three counties in New Mexico (Chaves, Eddy, and Lea) and parts of seven counties in Texas (Andrews, Culberson, Gaines, Loving, Reeves, Ward, and Winkler). Seventy-five percent of the ROI lies within New Mexico, and the remaining 25 percent lies within Texas.

The following population data are derived from the 1990 Census of Population and Housing (U.S. Bureau of the Census 1994). Within the Environmental Justice ROI, the total population of 101,129 persons includes 4.1 percent non-White, 32.6 percent Hispanic, and 36.8 percent minority (all except White non-Hispanic persons). In addition, 21.5 percent of the total population had 1989 incomes below the poverty level, as defined by the U.S. Bureau of the Census. There are no Native American reservations in the ROI. Figures 4-11and 4-12 display maps of the distribution of minority and low-income populations according to the percentage of the block group population in the environmental justice ROI. Block grouping is a division of territory, the size of which varies according to population density, that has approximately 400 households.

The proportion of Hispanic, minority, and low-income persons in the ROI are all greater than in the United States as a whole. Also, the proportion of low-income persons in the ROI is greater than in both New Mexico and Texas. Finally, the proportion of Hispanic persons in the ROI is smaller than in New Mexico but greater than in Texas.

[1] Towns in this ROI include Artesia, Atoka, Black River village, Carlsbad, El Paso Gap, Hope, Lakewood, Loco Hills, Loving, Malaga, Riverside, Seven Rivers, and Whites City in Eddy County, New Mexico and Eunice, Hobbs, Humble City, Jal, Lovington, Maljamar, Monument, Nadine, and Oil Center in Lea County, New Mexico. This ROI also includes Mentone in Loving County, Texas, and both Arno and Orla in Reeves County, Texas. The other counties in New Mexico and Texas that are part of this ROI have no communities within the 80-kilometer radius.

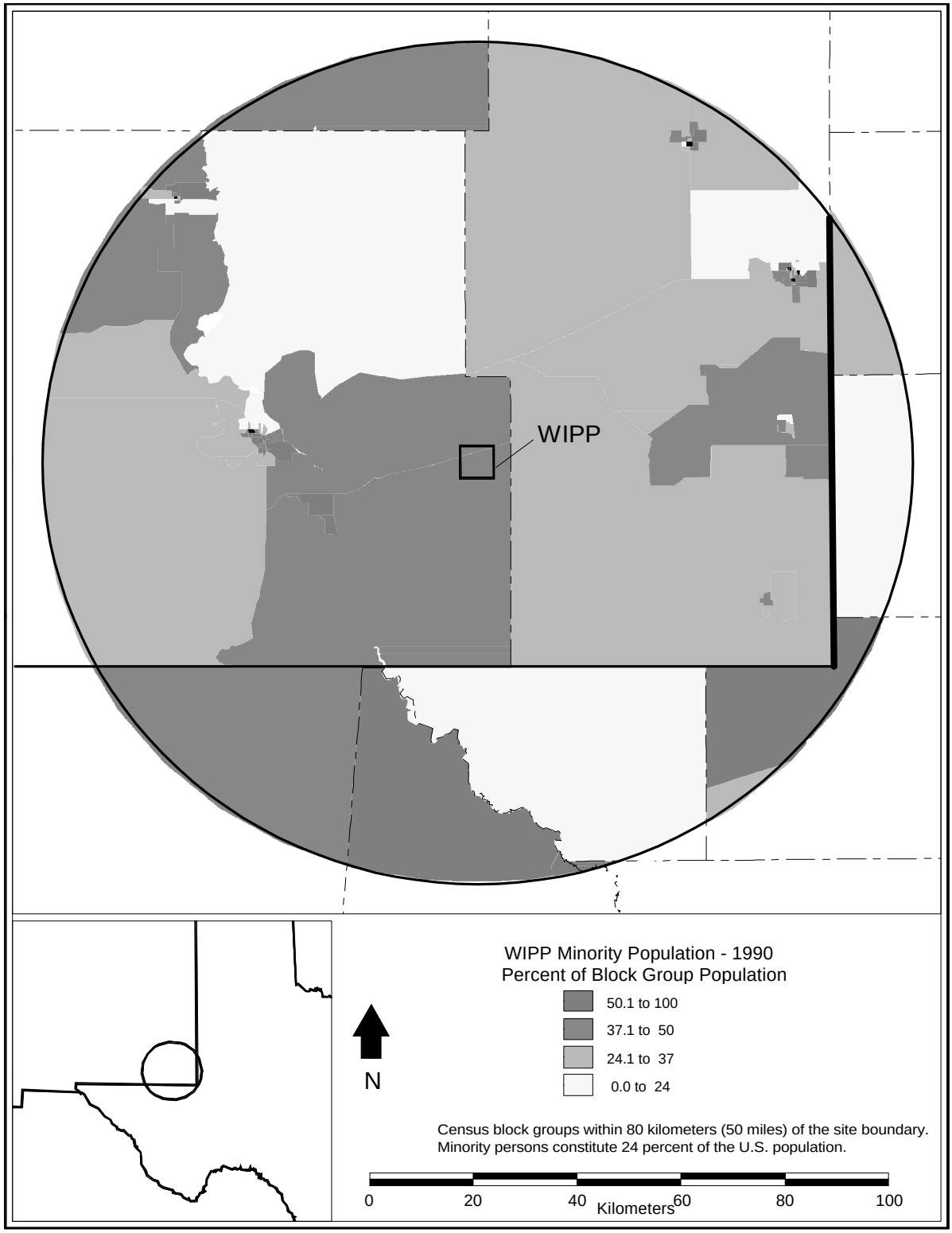


Figure 4-11
Minority Population

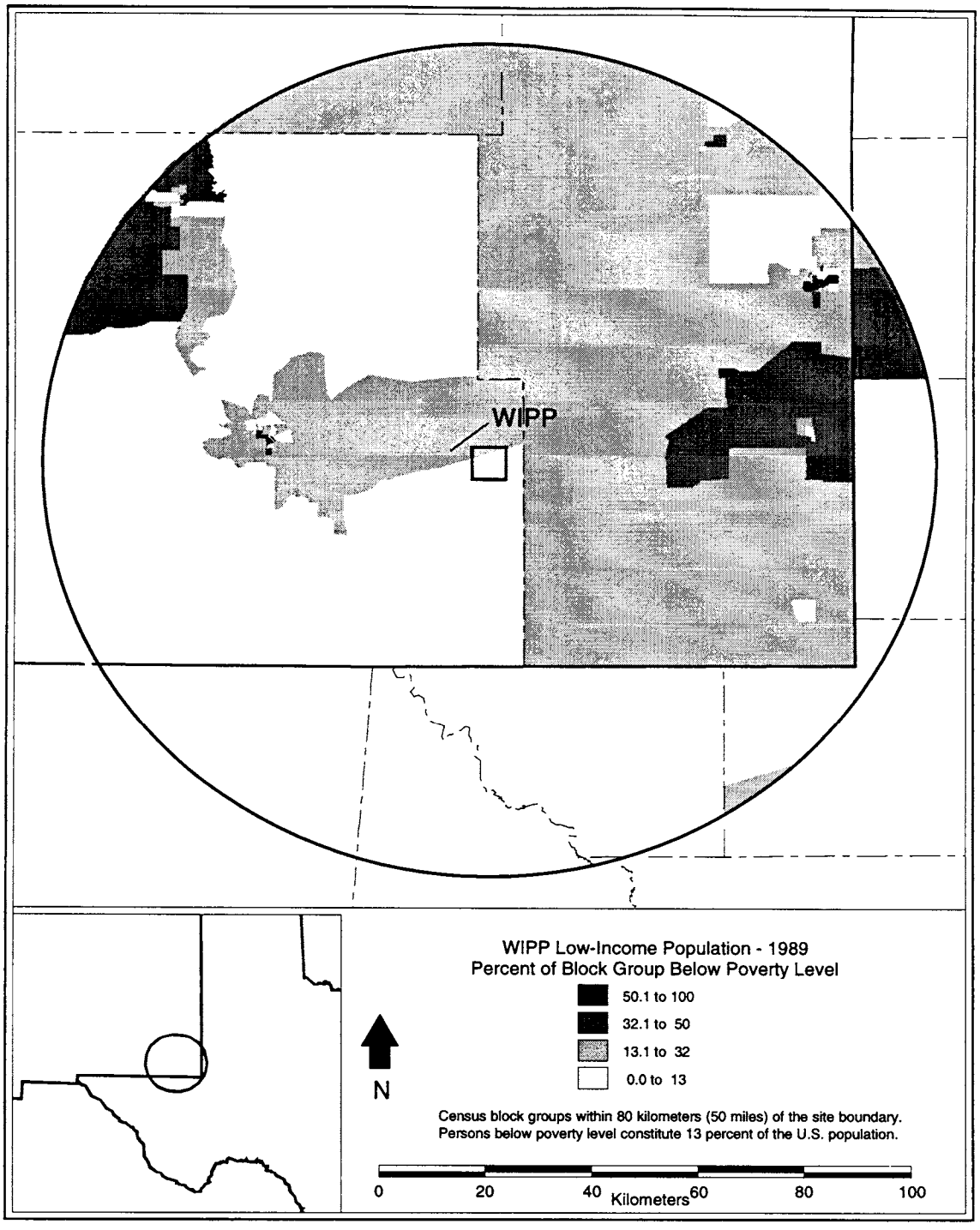


Figure 4-12
Low-Income Population

4.1.7 Transportation

SEIS-I briefly describes the transportation routes leading to WIPP. The site can be reached by rail or highway. DOE has constructed a rail spur to the site from the Burlington Northern and Santa Fe Railroad 10 kilometers (6 miles) west of the site. The site can also be reached from the north and south access roads constructed for the WIPP project. The north access road intersects U.S. Highway 62/180 (U.S. 62/180) 21 kilometers (13 miles) north of WIPP. The south access road intersects New Mexico Highway 128 6.5 kilometers (4 miles) to the southwest of WIPP. Transportation routes from principal DOE sites and facilities are shown in Appendix E, which also presents additional information on transportation methods and routes.

4.1.8 Background Radiation

The background radiation conditions in the vicinity of WIPP are influenced by natural sources of radiation, fallout from nuclear tests, and Project Gnome, a local research project (DOE 1990).

DOE established long-term radiological monitoring programs in southeastern New Mexico prior to the WIPP project, to determine the widespread impacts of nuclear tests at the Nevada Test Site (NTS) and to evaluate the effects of Project Gnome. The background radiation levels measured at WIPP from 1976 to 1979 are discussed in FEIS (DOE 1980).

The WIPP Radiological Baseline Program (RBP) was initiated in 1985 to describe background levels of radiation and radionuclides in the WIPP environment prior to the underground emplacement of radioactive waste (DOE 1990). The RBP consists of five subprograms: (1) atmospheric baseline, (2) ambient radiation (gamma radiation), (3) terrestrial baseline (soils), (4) hydrologic baseline (surface water, bottom sediments, and groundwater), and (5) biotic baseline (radiological parameters in key organisms along potential radionuclide-migration pathways). Mean gross alpha activity in airborne particulates has shown little variation and is within the range of 1 to 3 x 10^{-15} microcuries per milliliter. Mean gross beta activity in airborne particulates fluctuates but is typically within the range of 1 to 4 x 10^{-15} and 1 to 4 x 10^{-14} microcuries per milliliter. The average level of gamma radiation in the environment is approximately 66 millirem per year. On average, a person in the United States receives an effective dose equivalent of about 350-360 millirem per year from all sources of radiation (DOE 1997b, 1995g). Radionuclide concentrations in soil, surface water, sediment samples, and key organisms fall within expected ranges and do not indicate any unexpected environmental concentrations (DOE 1990).

In 1994, atmospheric particulates, ambient radiation, soil, surface water and sediment, groundwater, and biota (vegetation, fish, rabbit, and deer) samples were collected throughout the year from a number of locations and analyzed radiologically. Table 4-5 highlights the radionuclides sampled in the WIPP vicinity. An estimated annual dose of approximately 65 millirem was determined, indicating that no unusual levels of environmental radioactivity exist at WIPP (DOE 1995d).

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Background Radiation - Since publication of SEIS-I, the WIPP Radiological Baseline Program (RBP) has shown that there has been little variation in mean gross alpha, beta, and gamma levels in airborne particulates. Radionuclide concentrations in soil, surface water, sediment samples, and key organisms have fallen within the expected ranges and have not indicated any excessively high environmental concentrations.

Table 4-5
Radionuclides Sampled in the Vicinity of WIPP

Name	Symbol	Particulate	Soil	Surface-water/ Sediment	Groundwater	Biota
Actinium-228	^{228}Ac			X		X
Beryllium-7	^{7}Be	X				
Potassium-40	^{40}K	X	X	X	X	X
Cobalt-60	^{60}Co	X	X	X	X	X
Strontium-90	^{90}Sr	X	X	X	X	X
Cesium-137	^{137}Cs	X	X	X	X	X
Radium-226/228	$^{226/228}Ra$	X	X	X	X	X
Thorium-228/230/232	$^{228/230/232}Th$	X	X	X	X	X
Uranium-233/234/235/238	$^{233/234/235/238}U$	X	X	X	X	X
Plutonium-238/239/240/241	$^{238/239/240/241}Pu$	X	X	X	X	X
Americium-241	^{241}Am	X	X	X	X	X
Lead-210	^{210}Pb	X	X	X	X	X
Polonium-210	^{210}Po	X	X	X	X	X

As discussed in FEIS (DOE 1980) and SEIS-I (DOE 1990), Project Gnome resulted in a nuclear device being detonated underground approximately 14 kilometers (9 miles) south-southwest of the WIPP site in 1961 as part of the Plowshare Program sponsored by the Atomic Energy Commission. In 1972, the EPA established a program to monitor radionuclide levels in surface water and groundwater in areas potentially affected by Project Gnome. EPA (1989) published the results in its "Off-Site Environmental Monitoring Report: Radiation Monitoring Around United States Test Areas, Calendar Year 1988." In June 1995, the Environmental Evaluation Group (EEG) conducted a limited radiological survey of the Project Gnome area (EEG 1995) as well as a radiochemical analyses with a commercial laboratory. The results indicated that there were elevated levels of plutonium-238 (Pu-238), plutonium-239 (Pu-239), plutonium-240 (Pu-240), and americium-241 (Am-241) in localized surface soils at the Gnome site. Although the results indicated measurable transuranic (TRU) contamination at the Gnome site, EEG reported that the levels did not appear to present any immediate health and safety concern.

4.2 EXISTING ENVIRONMENT AT THE TEN MAJOR GENERATOR-STORAGE SITES

The following sections briefly summarize the existing environments at the 10 major generator-storage sites listed in Chapter 1. Maps showing the locations of the sites can be found in Chapter 3.

4.2.1 Argonne National Laboratory-East (ANL-E)

ANL-E occupies 690 hectares (1,700 acres) in northeast Illinois, in DuPage County, approximately 35 kilometers (22 miles) southwest of downtown Chicago, Illinois. The site is north of the Des Plaines River valley, south of Interstate-55, and west of Illinois Highway 83. Comprised of several buildings, ANL-E is a multi-program laboratory that conducts basic and applied research in the areas of reactor development, physical sciences, and life and environmental sciences. Technology commercialization and science education are also ANL-E missions (META/Berger 1995).

Regional land use surrounding ANL-E is characterized by high concentrations of urban development, including commercial, industrial, public, and residential usage. Several large forest preserves are east and southeast of the site. The site itself is in a suburban area. ANL-E uses only 80 hectares (200 acres) of the site for DOE activities, devoting the rest to forest and landscape areas (META/Berger 1995).

Four on-site wells provide the water supply for ANL-E. An average of 3,000 to 3,400 cubic meters (800,000 to 900,000 gallons) of water is pumped from the wells each day. ANL-E is now in the process of converting from local groundwater supplies to a municipal supply obtained from Lake Michigan (Holdren et al. 1995). The current site load for electricity is 23 megawatts (META/Berger 1995).

The ANL-E is located in a Class II designated PSD air quality area. The nearest Class I designated PSD area is the Seney National Wildlife Refuge located approximately 525 kilometers (325 miles) north of the site in Seney, Michigan. The EPA classifies the site and the surrounding counties as severe nonattainment areas for the criteria pollutant ozone. All other surrounding counties and areas are in attainment of the remaining NAAQS criteria pollutants except for Lyons Township in southeast Chicago, which is listed as a moderate nonattainment area for PM_{10} (META/Berger 1995).

There are no known active tectonic features within 100 kilometers (62 miles) of the site. Several areas of considerable seismic activity are present at moderate distances from ANL-E, including the New Madrid fault zone in southeastern Missouri (a fault zone along the southern Illinois-Indiana border) and one in western Ohio. Horizontal accelerations greater than 0.1 gravity are estimated to occur on the site approximately once in 600 years (META/Berger 1995).

ANL-E is on the northern margin of the Des Plaines River valley. The largest on-site stream is Sawmill Creek, which originates north of the site and enters the Des Plaines River about 2 kilometers (1.25 miles) southeast from the center of the site. ANL-E is located approximately 46 meters (150 feet) above the Des Plaines River and thus is not subject to major flooding (META/Berger 1995). Sawmill Creek is currently the receiving body for effluent from ANL-E treatment facilities. The quality of waters in both Sawmill Creek and the Des Plaines River is poor. The Des Plaines River is used for neither agricultural nor domestic supplies for more than 100 kilometers (62 miles) downstream of ANL-E (Holdren et al. 1995).

ANL-E uses two principal aquifers for its water supply. The upper aquifer is about 60 meters (200 feet) thick and supplies potable water. The other aquifer is below the first, lying between 150 and 460 meters (500 and 1,500 feet) beneath the surface. The two aquifers are not directly connected and pumpage from the upper aquifer does not appear to affect the lower aquifer. No aquifers in the ROI are considered sole source aquifers under Safe Drinking Water Act regulations (META/Berger 1995).

Federal-listed threatened or endangered species are not known to reside on the ANL-E site. The site is known to contain one state-listed endangered bird. Six federally- or state-threatened or endangered species reside in the area and may possibly reside on the site (META/Berger 1995).

As of 1994, a complete survey of ANL-E revealed 43 prehistoric and 6 historic archeological properties, but no sites listed with the NRHP or designated as National Historic Landmarks. Three sites are potentially eligible for the NRHP, 20 sites are not considered eligible, and 26 sites have

not been evaluated. The potential of ANL-E to contain traditional cultural resources of interest to Native American groups has also not been evaluated (META/Berger 1995).

The counties of DuPage, Cook, Kane, and Will, in Illinois comprise the economic ROI in which 95.4 percent of all ANL-E's employees reside. About 4,500 persons were employed at ANL-E. The ROI total population in 1992 was 6,568,800, of which approximately 98 percent was urban. Within the ROI, Whites comprise approximately 68.5 percent of the population, Blacks comprise 21.2 percent, and Hispanics comprise 12.1 percent. In 1989, about 9 percent of all families were below the poverty level. The dominant industries in the ROI include manufacturing, finance, insurance, real estate, and government (META/Berger 1995).

The ANL-E ROI is served by Interstate Highways 55, 80, 294, and 355. In addition, U.S. Routes 34 and 45/20 and Illinois Route 83 provide local access. The Chicago metropolitan area has a number of rail lines which can be accessed by truck from ANL-E. The nearest major airport is Chicago's O'Hare International Airport (META/Berger 1995).

Radionuclide sampling at ANL-E is carried out for soil, water, and air. The 1990 data indicated no substantial difference between on-site and off-site radionuclide concentrations in soil samples. In 1993, measurable levels of several radionuclides were detected in Sawmill Creek downstream from the wastewater treatment plant outfall. The concentrations of all these radionuclides were only a small fraction of the DOE-derived concentration guides for water. In 1993, elevated levels of Am-241, cesium-137 (Cs-137), cobalt-60 (Co-60), and Pu-239 were found in sediments below the outfall and are attributed to past releases. Radionuclides found in groundwater include Cs-137, strontium-90 (Sr-90), and tritium (H-3). In 1993, all radionuclide monitoring results were less than the limits established by the Safe Drinking Water Act. Airborne particulates and other airborne sources added to the background radiation in the ANL-E area.

The annual radiation dose to the population residing within 80 kilometers (50 miles) of the site from normal accident-free operations during 1994 would result in 3×10^{-3} latent cancer fatalities (LCFs). The population within this area was 7,900,000. The annual dose from airborne radionuclides to the maximally exposed individual (MEI) during 1994 would result in a 8×10^{-9} probability of an LCF. The corresponding dose is below the National Emission Standard for Hazardous Air Pollutants (NESHAP) limit.

4.2.2 Hanford Site (Hanford)

Hanford covers about 1,450 square kilometers (560 square miles) of the southeastern part of the state of Washington in parts of Benton, Grant, and Franklin Counties. The nearest city, Richland, Washington, borders the site on its southeast corner. The site is bounded on the east by the Columbia River, on the west by the Rattlesnake Hills, and on the north by Saddle Mountain. The site has a number of facilities including retired plutonium production reactors, operating reactors, waste management and spent nuclear fuel processing facilities, and nuclear research and development laboratories (DOE 1995a).

Land on the Hanford site is used primarily by DOE. However, there are also areas used as a wildlife refuge and for game management. The land adjacent to the site is either urban, commercial, or agricultural. Agricultural areas include irrigated and dry-land farming and grazing. The Columbia River adjacent to the site is heavily used for recreation (DOE 1995a).

The Columbia River is the principal source of water for Hanford. In 1992, the site consumed approximately 15 million cubic meters (4 billion gallons) of water. The Bonneville Power Administration provides electricity. In 1992, electricity consumption at the site was approximately 340,000 megawatt-hours, with a power demand of 57 megawatts (DOE 1995a).

Air quality in the Hanford region is well within the State of Washington and EPA standards for criteria pollutants, except that short-term particulate concentrations occasionally exceed the PM_{10} standard (DOE 1995a). Hanford is in a Class II air quality area (META/Berger 1995). The Class I areas nearest to the site are Goat Rocks Wilderness Area and Mount Rainier National Park, both about 145 kilometers (90 miles) away. Two other Class I areas are within 175 kilometers (110 miles) of the site (DOE 1995a).

The climate of the area is semiarid, with hot, dry summers and cool winters. Temperatures range from an average high of 2 degrees Celsius (36 degrees Fahrenheit) in January to an average high of 35 degrees Celsius (95 degrees Fahrenheit) in July (DOE 1995a). On average, thunderstorms occur 11 days per year, mostly in summer. The annual average precipitation is 16 centimeters (6.3 inches). The prevailing wind is from the west and the monthly average wind speeds range from 3 meters per second (7 miles per hour) in the winter to 4 meters per second (9 miles per hour) in the summer (META/Berger 1995). Tornadoes are extremely rare, occurring within 160 kilometers (100 miles) of the site about once every three years. The estimated probability of a tornado striking a point on the site is 9.6×10^{-6} per year.

Hanford is on a low-lying, modified plain of the Columbia River. Recent alluvial or windblown sands comprise the surface of the plain, with basaltic lava flows and various layers of gravel, silts, and clays underneath (DOE 1995a).

Earthquake activity in the area of Hanford has historically been low-to-moderate. The site is in a Uniform Building Code Seismic Risk Zone 2B. The largest shock recorded near the site was approximately 4.5 to 5.0 on the Richter scale (Modified Mercalli Intensity of V) in Corfu, 35 kilometers (22 miles) north of the site, in 1918. Another Modified Mercalli Intensity V quake occurred in the area in 1973. The site often experiences low intensity earthquakes occurring in clusters over a short period of time. Volcanic hazards are low as the site is located approximately 160 kilometers (100 miles) east of the Cascade Range, which includes several volcanic vents. Foreseeable volcanic effects at the site are limited to windborne volcanic ash (DOE 1995a).

The Columbia River passes through the northern part of Hanford and forms part of the eastern boundary. The Yakima River is located near the southern portion of the site. There are also two intermittent creeks. Upstream dams control potential flooding from the Columbia River. Minor flooding away from on-site facilities occurs from the other watercourses. The water quality of the Columbia River is high, and the river contributes to the water supply for the site and for nearby cities. Radiological monitoring shows low levels of radionuclides in the river, considerably below concentration guidelines established by EPA drinking water standards. Wastewaters are discharged to several ponds on the site and the Columbia River. Nonradiological contaminant concentrations are within Washington State Water Quality Standards (DOE 1995a).

There are unconfined aquifers located beneath Hanford (DOE 1995a). No aquifers are considered sole-source aquifers (META/Berger 1995). In 1993, several radionuclides and nonradioactive chemicals were detected at levels exceeding EPA drinking water standards and/or DOE derived

concentration guides (DOE 1995a). Preliminary investigations have identified four major groundwater contaminant plumes that have been found to enter the Columbia River in at least three locations (META/Berger 1995). Groundwater beneath the site is not used for human consumption or food production, except for one well used for drinking at one of the facilities. Above-background levels of radionuclides have been detected in this well; however, the levels are considerably below EPA drinking water standards (DOE 1995a).

Hanford, a shrub-steppe environment dominated by cheatgrass and sagebrush, includes 10 different types of plant communities. Deer and elk are the major large animals, and coyotes are the main large predators (DOE 1995a). Wetlands existing along the Columbia River and other streams and seeps support extensive stands of various types of vegetation as well as the waterfowl that use them for nesting. The river supports 44 species of fish, including salmon and trout, which use it as a spawning area (META/Berger 1995). A 310-square-kilometer (120-square-mile) area of the site set aside for ecological studies, a wildlife refuge, and a game management area comprises the Arid Land Ecology Reserve.

The entire Hanford site has been designated a National Environmental Research Park (NERP) (DOE 1995a). There are six federal- or state-threatened or endangered species of birds on the Hanford site. One state-endangered mammal and four state-threatened or endangered plant species are also found. In addition, there are 12 other species of animals which are federal- or state-classified as species of concern (META/Berger 1995).

As of 1992, 248 prehistoric archeological sites were recorded, 48 of which are on the NRHP (DOE 1995a). In addition, 11 historic archeological sites and 11 other properties are also listed on the NRHP (META/Berger 1995). Archeological sites include the remains of villages, campsites, cemeteries, monuments, hunting sites, and quarries. Several Native American groups retain traditional secular and religious ties to the region. Some native plant and animal foods used in religious ceremonies can be found on the Hanford site (DOE 1995a).

The primary socioeconomic impact area includes the tri-cities (Richland, Kennewick, and Pasco) and the counties of Franklin and Benton in Washington state. The estimated population for this area in 1992 was about 160,000. The larger economic ROI includes eight other counties in both Washington and Oregon. The estimated population for this ROI in 1992 was about 550,000. The primary economies of the economic ROI, each employing about 40,000 to 50,000 people, include agriculture/fishing/lumbering, manufacturing, trade, services, and government (DOE 1995a). The environmental justice ROI, which is the area within an 80-kilometer (50-mile) radius from the site, contains about 380,000 people. This ROI population includes 20 percent minority, 18 percent low-income (DOE 1995a), and 19 percent Hispanic (META/Berger 1995). The site employs about 14,200 people, accounting for almost 25 percent of the nonagricultural employment in Benton and Franklin Counties. These two counties also account for approximately 93 percent of site employees (META/Berger 1995).

DOE has entered into agreements with the tribal governments representing the Yakama Indian Nation, Nez Perce Tribe, and the Confederated Tribes of the Umatilla Indian Reservation. These agreements pertain to the core environmental programs and the emergency preparedness and response program.

U.S. Highways 12 and 395, Interstate-82, and State Route 240 run through the Hanford site. Two railroads also connect the area with much of the rest of the nation.

High-level radioactive waste has been accumulating at Hanford since 1944. Before 1970, TRU waste was disposed of on-site in unlined trenches; since 1970, however, Hanford has stored TRU waste in aboveground storage facilities. Besides high-level radioactive waste, the site also has low-level waste, mixed waste, and hazardous waste stored in large amounts. Hanford is included on the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) National Priorities List.

In 1993, radiation workers at the site were monitored and found to have average annual doses resulting in an 8×10^{-6} probability of an LCF per individual (DOE 1995a). The annual radiation dose to the population residing within 80 kilometers (50 miles) of the site from normal accident-free operations during 1994 would result in 2×10^{-4} LCFs. The population within this area was 380,000. The annual dose from airborne radionuclides to the MEI during 1994 would result in a 3×10^{-9} probability of an LCF. The corresponding dose is below the NESHAP limit. About 50 cancer deaths could be projected by the total public radiation dose from Hanford activities since 1944. Essentially all of these would have been the result of radiation exposures received during 1945 (DOE 1995a).

4.2.3 Idaho National Engineering and Environmental Laboratory (INEEL)

INEEL encompasses 230,000 hectares (568,000 acres) within five counties in southeastern Idaho. The site is located 44 kilometers (27 miles) west of Idaho Falls, Idaho, on the Eastern Snake River Plain in the Basin and Range Province of North America. The site is bordered by mountain ranges and volcanic buttes (DOE 1995a).

Land at INEEL is used for DOE operations, recreation, grazing, and environmental research. About 2 percent of the total INEEL site area (4,600 hectares [11,400 acres]) is used for facilities and operations. Recreational uses include public tours of general facility areas and controlled hunting. Between 121,000 and 142,000 hectares (300,000 and 350,000 acres) are used for cattle and sheep grazing. BLM does not allow grazing within 3 kilometers (2 miles) of any nuclear facility, and, to avoid the possibility of milk contamination by long-lived radionuclides, does not permit dairy cattle anywhere on the site. BLM also manages some of the undeveloped areas for wildlife habitat. No mineral exploration or development is allowed on INEEL land (DOE 1995a).

Site activities at INEEL withdraw an average of 7.4 million cubic meters (1.9 billion gallons) of groundwater per year. The peak demand on the INEEL electric system from 1990 to 1993 was about 40 megawatts, and the average usage was approximately 200,000 megawatt-hours per year (DOE 1995a).

The Craters of the Moon National Monument is 25 kilometers (15 miles) southwest of INEEL's western boundary and is in a designated Wilderness Area for which Class I air quality standards must be maintained. Concentrations of criteria pollutants at the site are below the NAAQS, state, and PSD standards and limits. The estimated on-site concentrations of most toxic air pollutants are well below levels established for protection of workers. The maximum short-term benzene concentration slightly exceeds the standard at the highest predicted location. For off-site conditions, all toxic air pollutant levels are below reference levels (DOE 1995a).

INEEL has an arid climate, with low relative humidity, wide daily temperature fluctuations, and large variations in annual precipitation. Thunderstorms occur 2-3 days per month during the

summer; otherwise, severe weather is uncommon. No tornadoes were reported on-site from 1950 to 1988. The mean annual temperature is 5.6 degrees Celsius (42 degrees Fahrenheit) and the mean annual precipitation is 22 centimeters (8.7 inches) (DOE 1995a). Notable variations in wind direction and speed are characteristic of the INEEL site. The prevailing wind direction ranges from west-southwest to north, and the average wind speed is about 3.2 meters per second (7.2 miles per hour) (Holdren et al. 1995).

The surface at the INEEL site is comprised primarily of basaltic lava flows ranging in age from about 2,000 years to over 1 million years. The site also contains wind-blown loess and sand and floodplain sediments. Volcanic hazards at INEEL can come from sources inside or outside the boundary of the site. Regional major volcanic activity has occurred at Craters of the Moon National Monument as recently as 2,100 years ago and at Yellowstone National Park (160 kilometers [100 miles] away) three times within the past 2 million years. The probability that volcanism would affect an INEEL site facility is less than 2.5×10^{-5} per year (DOE 1995a).

There are volcanic rift zones lying across INEEL, and the surrounding basin and range landscape also has frequent earthquakes (DOE 1995a). Two major earthquakes, of magnitude 7.3 and 7.5, have occurred within 100 miles of the site during the last 35 years (DOE 1996b). However, based on the seismic history and geologic conditions, earthquakes greater than magnitude 5.5 are unlikely within the site, though moderate to strong ground shaking from earthquakes within the nearby basin and range areas can affect the site (DOE 1995a).

The INEEL site is covered with wind-blown sediments generally less than 2.1 meters (7 feet) deep (DOE 1995a). These soils have a low-to-moderate water erosion hazard and a moderate-to-high wind erodibility (DOE 1995g).

INEEL is located in the Mud Lake-Lost River Basin, a closed drainage basin that includes three main tributaries (the Big and Little Lost Rivers and Birch Creek) which together drain approximately 753,000 hectares (1,860,000 acres). The Big Lost River crosses the site to an area of playas, or sinks, where water is discharged during an unusually wet year. However, surface water from this river, as well as the Little Lost River, does not usually reach the site. Water from Birch Creek flows into the site during the winter and infiltrates into channel gravels, where it recharges a local aquifer (DOE 1995a). During most years, all surface waters in the Little Lost River and Birch Creek are diverted to irrigation before entering the site (Holdren et al. 1995). Local flooding can occur at the site when the ground is frozen and runoff from melting snow is combined with heavy spring rains (DOE 1995a).

Chemical and radioactive parameters measured in the three rivers have not exceeded applicable drinking water quality standards. INEEL site activities do not directly affect the quality of surface water outside the site because surface water does not flow directly off-site. Discharges from facilities are made to manmade seepages and evaporation basins, rather than natural surface water bodies (DOE 1995a).

INEEL overlies the Snake River Plain Aquifer, the largest in Idaho, designated as a sole-source aquifer. This aquifer is also the source of all water used at INEEL. The depth to groundwater from the surface ranges from approximately 60 meters (200 feet) to over 270 meters (900 feet). Groundwater quality is affected by natural water chemistry and contaminants originating at INEEL facilities. Concentrations of radionuclides in the aquifer have decreased over time, primarily due to reduced discharges, adsorption, radioactive decay, and improved waste management practices.

Inside the site boundary, several radionuclide concentrations have exceeded the EPA maximum contaminant levels for drinking water. Outside the site boundary, all contaminant levels measured have been below the EPA levels (DOE 1995a). INEEL is included on the CERCLA National Priorities List.

INEEL site vegetation includes saltbrush deserts, juniper woodlands, native grasslands, big and low sagebrush, and riparian communities. Big sagebrush is dominant, covering approximately 80 percent of INEEL (DOE 1996b). The USFWS National Wetlands Inventory maps show over 130 potential wetlands, most found near the rivers and associated playas. As of December 1994, at least one area at the Big Lost River sinks was found to meet the criteria for jurisdictional wetland delineation by the United States Army Corps of Engineers (DOE 1995a). In 1975, DOE designated most of INEEL as a NERP (DOE 1995g).

Several migratory species use the INEEL site for part of the year. Two federal-endangered and nine federal species of concern were identified as potentially occurring on the site. Two state-protected and ten state species of special concern also potentially occur on the site. No federal- or state-listed plant species were identified as potentially occurring. Eight plant species considered sensitive, rare, or unique are known to occur (DOE 1995a).

INEEL contains paleontological fossil sites and numerous prehistoric archeological sites. As of June 1994, more than 100 cultural resource surveys have been conducted, and over 1,500 archeological resources have been identified. Over 700 of these resources are considered to be potentially eligible for NRHP. The Experimental Breeder Reactor-I is a national historic landmark. INEEL contains many resources culturally important to the Shoshone-Bannock Tribes. These include not only cultural sites but also features of the natural landscape. In accordance with federal laws and in consideration of DOE's Native American policy, DOE has committed to additional interaction and exchange of information with the Shoshone-Bannock Tribes of the nearby Fort Hall Indian Reservation and is developing procedures for consultation and coordination at INEEL (DOE 1995a).

The socioeconomic ROI is a 7-county area where over 95 percent of INEEL's approximate 6,400 employees reside (DOE 1996b). The ROI labor force was 104,654 in 1991, and the 1990 population was 219,713 (DOE 1995a). About 2.5 percent of this population was Native American, and 5.5 percent was Hispanic (META/Berger 1995). The population within an 80-kilometer (50-mile) circle centered at Argonne National Laboratory-West (on the INEEL site) contains 7 percent minority and 14 percent low-income. Retail trade and educational services are the two largest employment sectors in the ROI, accounting for 17.6 percent and 11.4 percent of employment, respectively (DOE 1995a). In 1990, the per capita income for the ROI was $14,622 (META/Berger 1995).

DOE has entered into an agreement with the tribal governments representing the Shoshone-Bannock Tribes of the Fort Hall Indian Reservation. This agreement is designed to enhance Tribal technical and scientific capability in the areas of environmental restoration, emergency preparedness and response, and management of cultural resources.

About 144 kilometers (90 miles) of paved public highway run through the INEEL site. Railroads also serve the area, and a rail line into INEEL connects the towns of Arco and Blackfoot.

The annual radiation dose to the population residing within 80 kilometers (50 miles) of the site from normal accident-free operations during 1994 would result in 2×10^{-4} LCFs. The population within this area was 120,000. The annual dose from airborne radionuclides to the MEI during 1994 would result in a 2×10^{-9} probability of an LCF. The corresponding dose is below the NESHAP limit. In addition, DOE estimates no adverse health effects from any noncarcinogenic chemical contaminants (DOE 1995a).

4.2.4 Lawrence Livermore National Laboratory (LLNL)

LLNL includes the Livermore site, the adjoining Sandia National Laboratories, California site (SNL-CA), and the LLNL experimental test site (Site 300). The Livermore site is approximately 64 kilometers (40 miles) east of San Francisco, California, and about 5 kilometers (3 miles) east of Livermore, California. The SNL-CA site is located next to and south of the Livermore site. Site 300 is about 24 kilometers (15 miles) southeast of Livermore in the sparsely populated hills of the Diablo Range. Today, the major programs at LLNL include defense and related programs, laser fusion, laser isotope separation, biomedical and environmental research, and environmental restoration and waste management (META/Berger 1995).

The Livermore and SNL-CA sites are at the southeast end of Livermore Valley in southern Alameda County. Site 300 is in a mostly rural area of San Joaquin County. Land adjacent to LLNL is predominantly private and consists of agricultural, residential, and light/industrial lands, with a smaller portion of public lands (META/Berger 1995).

The water supply for LLNL is provided by San Francisco's Hetch Hetchy water system. The current site load for water is 2,714,000 liters (717,000 gallons) per day and the maximum capacity is 9.54 million liters (2.52 million gallons) per day. The Pacific Gas and Electric Company and the Western Area Power Administration supply power to LLNL. The current site load is 61 megawatts. The maximum capacity is 100 megawatts (META/Berger 1995).

The Livermore site is in the San Francisco Bay Area Interstate Air Quality Control Region. This region has been classified as a nonattainment area for two criteria pollutants: CO and O_3. The Livermore site is in a Class II area, and any new sources of emissions must adhere to the increment standards for a Class II area (META/Berger 1995). Site 300 is located within the San Joaquin Valley Unified Air Pollution Control District. This area is classified as a nonattainment area for O_3 and PM_{10}. Several PSD Class I areas have been designated in the vicinity of LLNL, including Point Reyes National Wilderness Area, approximately 89 kilometers (55 miles) northwest of the Livermore site; Desolation National Wilderness Area; Mokelumne National Wilderness Area; Emigrant National Wilderness Area; Hoover National Wilderness Area; and Yosemite National Park. Since the promulgation of the PSD regulations in 1977, no PSD permits have been required for any emission source at the Livermore site (DOE 1996b).

The climate at LLNL and the surrounding region is classic Mediterranean with hot dry summers and cold wet winters. The average annual temperature is 12.5 degrees Celsius (54.5 degrees Fahrenheit). The temperature range at Site 300 is more extreme than at the Livermore site because of the higher elevation and pronounced relief (DOE 1996b). Annual precipitation at the SNL-CA ranges from 30 to 38 centimeters (12 to 15 inches) (META/Berger 1995).

All three sites lie within Seismic Zone 4 (DOE 1996b). The San Andreas fault system, the Sur-Nacimiento fault system, and the Coast Range thrust fault system are the major fault systems in the area. Along with local faults, these major regional faults are potential sources of ground motion at LLNL. In January 1980, an earthquake sequence on a local fault produced two earthquakes of magnitudes 5.5 and 5.6. These earthquakes caused structural damage at the Livermore and SNL-CA sites. Larger earthquakes on more distant faults, such as the San Andreas, do not substantially affect the hazard estimation for LLNL. The potential for surface faulting within the Livermore site is very low. Surface faulting at Site 300 in areas adjacent to the active Carnegie fault is possible (META/Berger 1995).

The main surface water features at the Livermore site are the Arroyo Las Positas and Arroyo Seco. Both stream channels are dry for most of the year. Two areas on the Livermore site are within the 100-year floodplains of these two streams; however, no existing on-site structures are within the 100-year floodplain. There are no perennial streams at or near Site 300. The canyons that dissect the hills and ridges at Site 300 drain into intermittent streams. The majority of these on-site streams drain to the south into Corral Hollow Creek, also intermittent, which flows east along the southern boundary of Site 300 in San Joaquin Valley. In addition to these streams, 24 springs and 2 vernal pools exist on-site. Some surface water discharge occurs from cooling towers and other process runoff areas (DOE 1996b).

Groundwater in the vicinity of the Livermore site is generally suitable as a domestic, municipal, agricultural, and industrial supply, with the exception of groundwater less than 90 meters (300 feet) deep. This groundwater is routinely monitored for radioactive and nonradioactive parameters. In 1993, the maximum concentrations of gross alpha, nitrate/nitrite, trichloroethylene, and tritium were above their water quality criteria or standard. The maximum concentrations found for tritium are in one local on-site well and pose no threat to water supplies. VOCs have also been detected in the on-site groundwater and in the area around the Livermore site. All site practices known to contribute VOCs to groundwater have been discontinued. LLNL is working with EPA and the State of California to identify appropriate remedial measures (DOE 1996b).

Two regional aquifers have been identified at Site 300. These are an upper water table aquifer of the Neroly Formation and a deeper confined aquifer also in the Neroly Formation (META/Berger 1995). At Site 300, groundwater is sampled quarterly from inactive and active water supply wells and monitoring wells, and analyzed for radioactive and nonradioactive parameters. Maximum concentrations of arsenic, gross alpha, nitrate/nitrite, trichloroethylene, tritium, and uranium were above their water quality criteria or standard at least once in 1993. LLNL is included on the CERCLA National Priorities List. LLNL is investigating and identifying characteristics of groundwater contamination at Site 300. Several plumes of VOCs and tritium have been identified in shallow and deeper bedrock aquifers in this area and several adjacent off-site areas. LLNL is working with the EPA and the State of California to remediate these plumes (DOE 1996b).

Fifty-nine federal- and state-listed threatened, endangered, and other special status species may be found on and in the vicinity of the Livermore site. Ten of these species have been observed on the site, including the federal-listed bald eagle (*Haliaeetus leucocephalus*). Thirty federal- and state-listed threatened, endangered, and other special status species have been observed on Site 300, and an additional 32 may be found on and in the vicinity of the site. These species include the federal-listed San Joaquin kit fox (*Vulpes macrotis mutica*), American peregrine falcon (*Falco peregrinus anatum*), large-flowered fiddleneck (*Amsinckia grandiflora*) and bald eagle; and the

federal-proposed Alameda whipsnake (*Masticophis lateralis euryxanthus*) and California red-legged frog (*Rana aurora draytoni*). Although suitable habitats for several of the other listed species exist on-site at LLNL, potential occurrence of most of the other species is minimal due to the lack of suitable habitat (DOE 1996b). No critical habitat for threatened or endangered species exists at LLNL (META/Berger 1995).

Since 1974, several archeological investigations have taken place at the Livermore site and Site 300. No prehistoric sites have ever been located at the Livermore site. A preliminary investigation at the Livermore site in 1992 explored the historic significance of World War II-era buildings and developed a potential context for initial consideration of the distinguished technical and scientific resources of LLNL. Cultural resource investigations at Site 300 have resulted in the discovery of 7 prehistoric sites, 21 historic sites, and 1 with elements of each. Of these, 24 are officially recorded, but no evaluations to determine site significance have been performed. Sacred and important Native American resources that might be found in the vicinity of LLNL include burials, cremations, vision quest sites, and traditional-use areas. Initial consultation with Native American groups to determine important resources has begun (DOE 1996b).

Four counties comprise the ROI in which 97.2 percent of the approximately 7,850 Livermore site and Site 300 employees reside. In 1990, the population in the ROI was 2,952,000. The population in the ROI is predominantly White (69 percent), and approximately 8.4 percent of the families were living below the poverty level in 1989. In 1991, the unemployment rate for the ROI was 9.3 percent. The 1990 per capita income in the ROI was $21,099. The dominant industries in the ROI include services, government, manufacturing, and retail, which account for 68.8 percent of total earnings (META/Berger 1995).

LLNL is serviced by Interstate-580, Interstate-5, and Interstate-680. South Vasco Road and Greenville Road, both of which are accessed from Interstate-580, service the Livermore site from the north. Patterson Avenue and East Avenue provide access to the Livermore site from the east and west. The Southern Pacific Railroad and the Western Pacific Railroad are the primary providers of rail service to the LLNL region (META/Berger 1995).

The annual radiation dose to the population residing within 80 kilometers (50 miles) of the site from normal accident-free operations during 1994 would result in 4×10^{-4} LCFs. The population within this area was 6,300,000. The annual dose from airborne radionuclides to the MEI during 1994 would result in a 3×10^{-8} probability of an LCF. The corresponding dose is below the NESHAP limit. The impact to the LLNL worker population from operations in 1994 was estimated to be 7.3×10^{-3} LCF (DOE 1996b).

4.2.5 Los Alamos National Laboratory (LANL)

LANL is located in north-central New Mexico, 97 kilometers (60 miles) north-northeast of Albuquerque, New Mexico, and 40 kilometers (25 miles) northwest of Santa Fe, New Mexico. The 11,300-hectare (28,000-acre) LANL site and adjacent communities are situated on the Pajarito Plateau (DOE 1995e). Since its inception in 1943, LANL's primary mission has been nuclear weapons research and development and related projects (META/Berger 1995). The land surrounding LANL is largely undeveloped, and large tracts of federal land surrounding the site are managed by the United States Forest Service, BLM, National Park Service, and Los Alamos County.

Three DOE-operated well fields provide an average of 15.5 million liters (4.1 million gallons) per day for LANL. Electricity usage in 1993 was 68 megawatts (META/Berger 1995).

LANL and its surrounding counties are considered attainment areas with respect to applicable NAAQS. The criteria pollutants make up approximately 79 percent of the stationary source emissions at LANL. Toxic and other hazardous pollutants represent the remaining 21 percent of the stationary source emissions. One PSD Class I area, Bandelier National Monument's Wilderness Study Area, borders LANL to the south. Since promulgation of regulations, no PSD permits have been required for any emissions source at LANL (DOE 1996b).

Los Alamos has a semiarid, temperate mountain climate. The annual average temperature at LANL is 8.9 degrees Celsius (48.1 degrees Fahrenheit) (META/Berger 1995). The average annual precipitation is 48 centimeters (18.7 inches) but is quite variable from year to year. Approximately 36 percent of the annual precipitation normally occurs from thunderstorms during July and August (DOE 1995e).

LANL is located on the Pajarito Plateau, which lies between the Jemez Mountains on the west and the Rio Grande on the east. Deep southeast-trending canyons, separated by long, narrow mesas, dissect the surface of the plateau (DOE 1995e). Studies have determined that the area has three active faults. The strongest earthquake in the past 100 years within a 80-kilometer (50-mile) radius had an estimated magnitude of 5.5 to 6 measured on the Richter scale and a Modified Mercalli Intensity of VII (META/Berger 1995). The site lies within Seismic Zone 2 (DOE 1996b), as established by the Uniform Building Codes.

All groundwater and surface water drainages from the Pajarito Plateau flow toward the Rio Grande. On-site tributaries to the Rio Grande include 14 drainage areas that pass through or start at LANL. Three of the canyons receive treated industrial or sanitary effluent. Surface water in these canyons is principally ephemeral and is not a source of municipal, industrial, or agricultural water supply. Regional, perimeter, and on-site surface waters are monitored to provide routine surveillance on the effect of LANL operations on water quality (META/Berger 1995). Surface water in the Los Alamos area principally occurs as short-lived or intermittent reaches of streams. The overall flood risk to LANL is low because nearly all the structures are located on the mesa tops, from which runoff drains rapidly into the deep canyons (DOE 1996b).

Groundwater in the LANL area occurs in four modes: shallow alluvium in canyons, perched water, the unsaturated zone between the surface and the main aquifer, and the main aquifer (DOE 1995e). Nearly all groundwater used at LANL originates from deep wells that produce water from the main aquifer. Under LANL are Class II aquifers, which provide current sources of drinking water and have other beneficial uses. Most of the wells in the Pajarito Plateau yield fresh water (total dissolved solids less than 500 milligrams per liter), although some wells east of the site have a higher total dissolved solids content (1,000 milligrams per liter or more). The primary, secondary, and radiochemical groundwater quality, as measured from wells and springs in the main aquifer, are below the DOE derived concentration guides or the New Mexico standards applicable to a DOE drinking water system. LANL and the nearby communities are entirely dependent on groundwater for their water supply (DOE 1996b).

The predominant vegetative communities at LANL are ponderosa pine, piñon-juniper, and juniper-grassland. LANL was designated a NERP in 1976 (META/Berger 1995). Most LANL wetlands occur in canyons. Wetlands have developed in the vicinity of some outfalls serving

LANL facilities. Thirty-four federal- or state-listed threatened, endangered, and other special status species may be found in the vicinity of LANL. Five of these species have been observed at LANL, but only one has been found to nest there and occupy the site year-round. Critical habitat for the Mexican spotted owl (*Strix occidentalis lucida*), a federally threatened species, exists at LANL and in areas bordering the northern and western boundaries of LANL (DOE 1996b).

Approximately 75 percent of LANL has been inventoried for cultural resources. More than 1,000 prehistoric sites have been recorded, and approximately 95 percent of these sites are considered eligible or potentially eligible for inclusion in the NRHP. Two areas in the vicinity of LANL have been established as NRHP sites or districts: Bandelier National Monument and Puye Cliffs Historical Ruins. Many of these cultural resources are of special importance to Native Americans in the area. Consultations with local Native Americans to identify any such cultural resources have been conducted in the past and are ongoing. More than 40 historic resources have been recorded at LANL, and about 90 percent of the resources are considered eligible or potentially eligible for the NRHP, based on their association with the broad historic theme of the Manhattan Project and initial nuclear production (DOE 1996b).

Three counties comprise the economic ROI in which 94.7 percent of LANL's 9,700 employees reside. In 1990, the population in the ROI was 152,300. The population in the ROI is predominantly White (79.8 percent) and 12.1 percent of the families are below the poverty level (META/Berger 1995). The 1994 unemployment rate in the ROI was 6.2 percent, and the per capita income in 1993 was $17,689. The service sector accounts for 31 percent of the nonfarm private sector employment in the ROI (DOE 1996b).

DOE has entered into an agreement with Tribal governments representing the Pueblos of Santa Clara, Cochiti, Jemez, and San Ildefonso. The purpose of this agreement is to build Tribal technical and scientific capability in environmental restoration and waste management and to assist the Tribes in participating in DOE decision making.

LANL is served by U.S. 84 and U.S. 285, which link Los Alamos to Santa Fe, New Mexico. U.S. 502, which can be accessed by U.S. 285 from Santa Fe, also services LANL. The nearest railway access is south of Santa Fe in Lamy, New Mexico (META/Berger 1995).

The annual radiation dose to the population residing within 80 kilometers (50 miles) of the site from normal accident-free operations during 1994 would result in 2×10^{-3} LCFs. The population within this area was 220,000. The annual dose from airborne radionuclides to the MEI during 1994 would result in a 4×10^{-6} probability of an LCF. The corresponding dose is below the NESHAP limit. Two epidemiological studies have recently been conducted in the LANL area. The most recent study presented an increased incidence of thyroid cancer in residents of Los Alamos county compared to the rest of New Mexico (DOE 1996b).

4.2.6 Mound Plant (Mound)

Mound is located in west-central Ohio, in Montgomery County, within the city limits of Miamisburg, Ohio, about 16 kilometers (10 miles) south-southwest of Dayton, Ohio (Holdren et al. 1995). Mound occupies about 124 hectares (306 acres) (DOE 1979) and is situated on the highlands overlooking the Great Miami River. Until December 1991, Mound manufactured nonnuclear components and tritium-containing components for nuclear weapons. Mound's current mission is environmental restoration and economic development (DOE 1994b). Land use and

cover within the vicinity of the Mound site is primarily residential and woodland, and on the site itself there are heavily wooded areas (Holdren et al. 1995).

The Air Quality Control Region comprising the facility has been classified as attainment of the NAAQS for NO_2, SO_2, and lead. However, EPA lists Montgomery County as nonattainment for O_3 and TSP (DOE 1995c). Operations at Mound emitted a wide variety of nonradioactive contaminants, such as organic solvents, acids, and metals (DOE 1989). Various radioactive contaminants such as Pu-238 and tritium were also released. The site is also a source of radionuclides due to resuspension of contaminated soils related to past practices. Recorded levels of these contaminants are well below DOE guidelines (DOE 1995c).

Tornadoes may touch down along short and narrow paths, but are infrequent in the region. Tornado wind speeds of 146 kilometers (90 miles) per hour or greater have an annual probability of occurrence of one in one thousand. Tornadoes with wind speeds exceeding 368 kilometers (227 miles) per hour have an annual probability of one in one million (DOE 1995c).

The major surface water feature in the area is the Great Miami River, located approximately 450 to 600 meters (1,500 to 2,000 feet) west of the site. The tributary valley between the two main hills contains a drainage ditch, the only perennial stream within Mound boundaries (Holdren et al. 1995). Surface water quality in the vicinity of Mound is satisfactory, with radioactivity levels far below established limits (DOE 1995b).

The major aquifer in the area, the Buried Valley Aquifer (also called the Great Miami Aquifer), is the major source of the area's potable water. Typically, groundwater occurs 6 to 8 meters (20 to 26 feet) below ground surface in the valley. The bedrock also contains groundwater but cannot provide a reliable source. The glacial tills overlying the bedrock may also contain perched water zones but are generally too thin to act as a water supply (Holdren et al. 1995). There has been minor contamination of the groundwater by Mound activities. Tritium and plutonium have been detected in the Miamisburg water supply at levels far below regulatory limits. Some on-site groundwater VOCs exceed EPA levels; however, off-site concentrations are far lower, with none exceeding EPA levels (DOE 1995b).

The site lies within the range of the Indiana bat (*Myotis sodalis*), a federally-listed endangered species. However, the bat has not been seen on-site, and habitats hosting the bat are not present at the site. A single specimen of the Inland rush (*Juncas interior weig*), a state-endangered plant species, was found but it is not considered a viable breeding population. No other rare or endangered species have been found on the site (DOE 1995b).

The only historic landmark in the vicinity of the site is the Miamisburg Mound, an ancient mound located 120 meters (390 feet) east-southeast of the site. It is believed to be a burial place of a member of the Adena culture of Mound Builders which inhabited the Ohio region in prehistoric times (DOE 1979). The site itself does not contain any properties listed or eligible for the NRHP (DOE 1995b).

The city of Miamisburg is largely residential, with limited commercial and industrial development. The 1990 population of the city was 17,770. Within an 8-kilometer (5-mile) radius of the site, the population is estimated to be 76,061, based on 1988 figures (DOE 1995b). The population rises to several hundred thousand within a 16-kilometer (10-mile) radius and to over one million within a

32-kilometer (20-mile) radius. The facility employs about 1,200 people, the majority of whom live either in Miamisburg or in immediately adjacent areas (DOE 1979).

Area routes include the Dayton-Cincinnati Pike, 0.6 kilometers (0.4 miles) west of Mound; State Route 725, 1.4 kilometers (0.9 miles) to the north; and Interstate-75, 5 kilometers (3 miles) to the east. The tracks of the Penn Central Railroad roughly parallel the western boundary of the site at distances ranging from approximately 15 to 60 meters (50 to 200 feet) (DOE 1979).

Mound is included on the CERCLA National Priorities List. There are 22 known radioactively contaminated soil areas on-site and one area off-site. Sediments in the Great Miami River also contain levels of radioactive material that are higher than background levels for the surrounding area. There are also approximately 100 areas on-site that are either known or suspected to be contaminated with nonradioactive hazardous substances (DOE 1989).

The annual radiation dose to the population residing within 80 kilometers (50 miles) of the site from normal accident-free operations during 1994 would result in 1×10^{-3} LCFs. The population within this area was 3,000,000. The annual dose from airborne radionuclides to the MEI during 1994 would result in a 2×10^{-8} probability of an LCF. The corresponding dose is below the NESHAP limit.

4.2.7 Nevada Test Site (NTS)

NTS occupies 3,500 square kilometers (1,350 square miles) of desert valley and Great Basin mountain terrain in southern Nevada, 105 kilometers (65 miles) northwest of Las Vegas, Nevada. Limited access areas, including the Nellis Air Force Base Bombing and Gunnery Range and the Tonopah Test Range, surround the site. The NTS has been the primary location for testing the nation's nuclear explosive devices since 1951 (META/Berger 1995).

Fourteen on-site wells supply an average of 5.15 million liters (1.36 million gallons) of water per day. The Nevada Power Company supplies electricity to NTS. The current site load is 30 megawatts (META/Berger 1995).

NTS is designated as an attainment or unclassified area with respect to all applicable NAAQS. Two PSD Class I areas in the vicinity of NTS are Grand Canyon National Park, Arizona, approximately 193 kilometers (120 miles) to the southeast and Sequoia National Park, California, located approximately 169 kilometers (105 miles) to the west-southwest of the site. Since promulgation of regulations, no PSD permits have been required for any emissions source at NTS (DOE 1996b).

NTS is in an area of moderate historic seismicity on the southern margin of the Southern Nevada East-West Seismic Belt in Seismic Zones 2 and 3. Since about 1848, more than 4,000 earthquakes have been recorded within a 242-kilometer (150-mile) radius of NTS. Most of these were minor events with Richter magnitudes of less than 5.5 (DOE 1995g). The Yucca fault is the only active fault on NTS within the underground nuclear testing area. The Rock Valley fault near the southern boundary of NTS has been the most active fault since 1990. (META/Berger 1995).

There are no continuously flowing streams at NTS, but there are permanent on-site water bodies, including natural springs and water-well overflow ponds, that are not associated with wastewater disposal. Sanitary wastewater influents to ponds and lagoons are regulated under a series of state

permits. Surface water bodies at NTS are routinely monitored for radioactive and nonradioactive parameters, and off-site surface water bodies and springs are also monitored for radionuclides (META/Berger 1995).

NTS has three general water-bearing units, and all are classified as Class IIA or Class IIB aquifers. Groundwater is the only source of drinking water in the NTS area. On-site wells are routinely monitored for radioactive and nonradioactive parameters, as required by the Safe Drinking Water Act, State of Nevada regulations, and DOE orders. Off-site groundwater is routinely monitored at 22 locations for radionuclides. Only three locations have evidenced detectable tritium levels on a consistent basis. In all three cases, the tritium activity has been less than 2 percent of the primary maximum contaminant level for tritium (20,000 picocuries per liter) (META/Berger 1995).

Thirteen federal- and state-listed threatened, endangered, and other special status species are present in the vicinity of NTS. The peregrine falcon is the only known species at NTS that is on the federal endangered species list. No critical habitat for threatened or endangered species exists on NTS (DOE 1996b).

Approximately 6 percent of NTS has been inventoried for cultural resources, and over 1,200 prehistoric sites have been recorded (DOE 1996b). Many of these sites may be eligible for listing on the NRHP. The only historic site that is currently listed is the Sedan Crater, which was created as part of the Plowshare Program to identify peaceful uses for nuclear explosions. Native American resources include ceremonial sites, petroglyphs, and traditional-use areas. Native Americans view many natural resources at NTS as cultural resources (DOE 1995g).

Two counties comprise the economic ROI in which 97 percent of the 1,600 NTS employees live. The ROI population totaled 865,144 in 1992 (DOE 1996b). The population in the ROI is predominantly White (81.5 percent), and in 1989, 7.5 percent of the population was below the poverty level (META/Berger 1995). During 1994, unemployment in the ROI was 6.1 percent. The 1993 per capita income in the ROI was $20,561. The service sector is the major economic sector in the ROI, with over half of the region's nonagricultural activity (DOE 1996b).

DOE has entered into two separate agreements with Consolidated Group of Tribes and Organizations to foster a government-to-government relationship and to encourage involvement in programs associated with NTS operations. This group is composed of 17 Tribes representing three ethnic groups (Western Shoshone, Owens Valley Paiute, and Southern Paiute) from Arizona, California, Nevada, and Utah, with cultural or historic ties to NTS.

Vehicular access to NTS is provided by U.S. Route 95 from the south and off-road access via State Route 375 from the northeast (DOE 1995a). Interstate-15 is the major transportation route in the region (META/Berger 1995). The major railroad in the area is the Union Pacific, which runs through Las Vegas and is located approximately 80 kilometers (50 miles) east of the NTS.

The annual radiation dose to the population residing within 80 kilometers (50 miles) of the site from normal accident-free operations during 1994 would result in 2×10^{-4} LCFs. The population within this area was 33,000. The annual dose from airborne radionuclides to the MEI during 1994 would result in a 8×10^{-8} probability of an LCF. The corresponding dose is below the NESHAP limit. Epidemiologic studies on groups surrounding NTS have concentrated on health effects in

soldiers and children associated with aboveground nuclear testing rather than operational emissions. Results are contradictory regarding the observed leukemia incidence and deaths in exposed children (DOE 1996b).

4.2.8 Oak Ridge National Laboratory (ORNL)

ORNL is part of the 13,980-hectare (34,545-acre) Oak Ridge Reservation (ORR) located 32 kilometers (20 miles) west of Knoxville, Tennessee, in the rolling terrain between the Cumberland Mountains and Great Smoky Mountains. The primary mission of ORNL is basic and applied research, technology development, and special DOE research. ORR also contains the Y-12 plant whose missions include dismantling nuclear weapons components, maintaining nuclear production capability and stockpile support, and providing storage for nuclear materials; and the K-25 site, which presently serves as an operations center for environmental restoration and waste management programs. The K-25 site formerly provided enriched uranium for United States nuclear weapons (DOE 1995g). The land surrounding ORR is primarily rural, dominated by agricultural and residential land (Holdren et al. 1995).

The Clinch River provides an average of 69.3 million liters (18.3 million gallons) of water per day to ORNL and ORR. The Tennessee Valley Authority provides electric power. The current site load is 116 megawatts (META/Berger 1995).

As of 1991, the area within the Air Quality Control Region was designated as attainment with respect to all NAAQS for criteria pollutants. The Great Smoky Mountains National Park is the only PSD Class I area in the vicinity of ORNL. Since the promulgation of regulations, no PSD permits have been required for any emissions source at ORNL (DOE 1995g).

Winters are generally mild and summers are warm, with few extremes in precipitation, temperature, or winds (DOE 1995g). Summer thunderstorms are frequent. Tornado occurrence in the general region averages about 0.5 per year (DOE 1995f). The annual average temperature is 14.2 degrees Celsius (57.5 degrees Fahrenheit). The annual average precipitation is 139 centimeters (55 inches) (DOE 1995g).

The topography, primarily ridge-and-valley, is part of the Tennessee Valley and Ridge Province of the Southern Appalachian fold and thrust belt (Holdren et al. 1995). There is no evidence of active faulting in the immediate area, although many inactive faults are present at ORNL (DOE 1995g). Regionally, earthquake frequency averages 1-2 per year (META/Berger 1995). Since 1812, at least 26 earthquakes with a Modified Mercalli Intensity of II to VI have been recorded in the area (DOE 1995f). ORNL lies within Seismic Zone 2, indicating that the probability of future seismic damage is low to moderate (META/Berger 1995). The site lies on moderately-well to well-drained soils. Soil erosion has ranged from light to severe, and the present erosion potential is high in some areas (DOE 1995g). The typical soil in the area is a reddish-brown clay (DOE 1997b).

The Clinch River and its tributaries are the major surface water features of the area (Holdren et al. 1995). ORR streams receive effluents from treated sanitary wastewater, industrial discharges, cooling water blowdown, stormwater, surface water runoff, and groundwater. Substantial cleanup activities are required both on-site and off-site (DOE 1995g).

Although groundwater occurs in all formations that outcrop at ORNL and ORR, three major hydrologic units are present. Mechanisms and rates of flow appear to be controlled by topography,

structure, and lithology (Holdren et al. 1995). There are no Class I sole-source aquifers beneath the site. Very little groundwater is used; only one supply well exists on ORR. Background groundwater quality is generally good in surface and bedrock aquifer zones and poor at depths greater than 305 meters (1,000 feet) due to high total dissolved solids. Hazardous chemicals and radionuclides from weapons production process activities have contaminated groundwater in some areas. The contaminated sites include past waste disposal sites, waste storage tanks, spill sites, and contaminated inactive facilities (DOE 1995g). ORR is included on the CERCLA National Priorities List.

ORR is heavily forested, with pine and pine-hardwood forest being the most extensive plant community, followed by oak-hickory forest (DOE 1995g). Approximately 20 percent of the site consists of wetlands; half of this is bottomland forest and half is pothole wetlands (META/Berger 1995). Approximately 5,500 hectares (13,590 acres) has been designated as a NERP (DOE 1995f). There are 88 federal- and state-listed threatened, endangered, and other special status species that have been identified on or in the vicinity of ORR. However, no critical habitat for threatened or endangered species exists on ORR (DOE 1995g).

More than 20 cultural resource surveys have been conducted on ORR. Over 45 prehistoric sites have been recorded, one site has been included in the NRHP, and several more are considered eligible. More than 240 historic resources have been recorded, and 50 of those sites may be eligible for the NRHP. The Graphite Reactor is a National Historic Landmark. There are also some resources that may be sensitive to Native American groups, including historic burial mounds, camps, quarries, chipping stations, limited activity locations, and shell scatters (DOE 1995g).

Four counties comprise the economic ROI in which about 92 percent of ORR employees live. The 1990 population of this ROI was about 489,000 (DOE 1995a). Minorities comprised 8.4 percent of this population, while 10.6 percent was below the poverty level (META/Berger 1995). The unemployment rate was 5.9 percent in 1991, and the per capita income was almost $17,000 (DOE 1997b). Major economic sectors include services, with over 26 percent of the region's total private sector nonagricultural activity; manufacturing (19 percent); and retail trade (17 percent) (DOE 1996b).

Interstate-40, located 2.4 kilometers (1.5 miles) south of the ORR boundary, provides the main access to the cities of Nashville and Knoxville, Tennessee. Interstate-75, located 24 kilometers (15 miles) south of the site serves as a major route to the north and south. Several state routes provide local access and form interchanges with Interstate-40. Railroad service is also available in the area (DOE 1995a).

The annual radiation dose to the population residing within 80 kilometers (50 miles) of the site from normal accident-free operations during 1994 would result in 2×10^{-2} LCFs. The population within this area was 940,000. The annual dose from airborne radionuclides to the MEI during 1994 would result in a 9×10^{-7} probability of an LCF. The corresponding dose is below the NESHAP limit.

4.2.9 Rocky Flats Environmental Technology Site (RFETS)

RFETS covers almost 17 square kilometers (7 square miles) in northern Jefferson County, Colorado. The site is located east of the foothills of the Rocky Mountains, approximately 25 kilometers (16 miles) northwest of Denver, Colorado. RFETS is situated in a generally rural

area with some ranches and industrial facilities nearby. Before January 1992, RFETS's primary mission was to produce nuclear weapon components from plutonium and other metals. The mission has now changed to decontamination and decommissioning, and the primary focus of the activities at RFETS is currently on environmental remediation and waste and materials management (META/Berger 1995).

The Denver Water Board from the Ralston and Gross Reservoirs provides the water supply for RFETS. Water is treated on-site at a plant with a maximum capacity of 3.8 million liters (1 million gallons) per day. The current site load for the treatment plant is 1.03 million liters (272,000 gallons) per day. The Public Service Company of Colorado supplies power to RFETS. The current site load for electricity is 18.3 megawatts (META/Berger 1995).

RFETS is located in an Air Quality Control Region that is a nonattainment area for the NAAQS criteria pollutants CO, O_3, and PM_{10} and an attainment area for the remaining criteria pollutants, SO_2, NO_2, and lead. Because the site is in a Class II PSD area, any new emission sources would have to adhere to the increment standards for a Class II area. The nearest Class I PSD area is Rocky Mountain National Park, approximately 50 kilometers (30 miles) northwest of RFETS (META/Berger 1995).

The climate in the area is semiarid. July is the warmest month, with daily maximum and minimum temperatures averaging 31 degrees Celsius (88 degrees Fahrenheit) and 15 degrees Celsius (59 degrees Fahrenheit), respectively. January is the coolest month, with daily maximum and minimum temperatures averaging 6 degrees Celsius (43 degrees Fahrenheit) and -9 degrees Celsius (16 degrees Fahrenheit), respectively. Annual precipitation is approximately 39 centimeters (15 inches), with about 80 percent falling from April through September (Holdren et al. 1995).

The topography at RFETS is generally flat except for areas along three creeks. Seismic activity in the area is low. An earthquake with a maximum horizontal acceleration of 0.21 gravity has an annual probability of occurrence of 1 in 5,000. The surface soils at the site are moderately deep, well-drained clay, cobbly clay, and sandy loams, with moderate-to-low permeability. Twenty-nine on-site locations monitor soil for plutonium contamination (META/Berger 1995).

There are five ephemeral streams at RFETS that form a west-to-east surface drainage pattern. The primary source of flood potential is from flash flooding in these streams; however, most facilities are located outside the 500-year floodplain. The site has seven National Pollutant Discharge Elimination System (NPDES) permitted outfalls, three of which discharge to surface waters that flow off-site. In 1992, only one case was reported in which the NPDES permit limits were exceeded, and this was for low pH at the wastewater treatment plant. Surface water is also monitored for radioactive and nonradioactive parameters in 3 on-site detention ponds. Monitoring of local drinking water supplies was discontinued in October 1992 (META/Berger 1995).

Groundwater systems at RFETS consist of a shallow, unconfined system in the Rocky Flats Alluvium and valley fill, and a confined system in the deeper sandstone units within the underlying bedrock. Recharge is from rainfall, snowmelt, leakage from other aquifers, and percolation from streams, ditches, and reservoirs. Discharge is by seeps, springs, base flow to streams, and evapotranspiration. Groundwater also leaves the area as subsurface flow. No aquifers in the area are sole source aquifers under the Safe Drinking Water Act regulations. The results of 1992

groundwater quality monitoring indicate that the groundwater in the area contains elevated levels of several VOCs, several radionuclides, and other contaminants (META/Berger 1995).

The major terrestrial communities at RFETS are mesic-mixed and xeric-mixed grassland (mixed tall- and short-grass communities), reclaimed grassland, riparian woodland, complex deciduous woodland and bottomland shrubland, tall upland shrubland, tall marsh, short marsh, and wet meadow. Wetlands represent 3.9 percent of the plant communities at RFETS and comprise a total of 100 hectares (250 acres). There are 40 federal- and state-listed threatened, endangered, proposed, candidate, and other special status species that are known to occur or may occur at RFETS (META/Berger 1995); in addition, the Preble's Meadow Jumping Mouse *(Zapus hudsonius preblei*) was recently proposed for federal listing.

RFETS has no properties designated as National Historic Landmarks or listed in the NRHP. According to the Colorado Historic Society, portions of the site have been the subject of at least three cultural resource investigations. The historic cultural resources in the area are archeological sites or standing structures associated with homesteads and ranching. Many Native American groups historically occupied or traversed the foothills area around RFETS. Important sites, such as burials or vision quest locations, and several unidentified rock features and alignments that have been recorded on RFETS may be of concern to Native American groups (META/Berger 1995).

Five counties comprise the economic ROI in which 92.5 percent of the site's 3,500 employees reside. In 1990, the ROI population was 1,790,600. The population was predominantly White (86.2 percent) with 7.2 percent of the total population living below the poverty level. In 1991, the unemployment rate for the ROI was 4.5 percent, and the per capita income in 1990 was $20,961. The dominant industries in the ROI include services, manufacturing, government, transportation and public utilities. These account for 68.1 percent of total earnings (META/Berger 1995).

The site is well served by both road and rail. Interstate-70, Interstate-25, and State Highways 72 and 93 serve the area. The city of Denver is a major railway hub in the Rocky Mountain region. A Southern Pacific line, approximately 1.6 kilometers (1 mile) south of the site, is the rail line nearest the plant and provides access to Denver. The nearest major airport is in Denver (META/Berger 1995).

The annual radiation dose to the population residing within 80 kilometers (50 miles) of the site from normal accident-free operations during 1994 would result in 1×10^{-4} LCFs. The population within this area was 2,100,000. The annual dose from airborne radionuclides to the MEI during 1994 would result in a 1×10^{-9} probability of an LCF. The corresponding dose is below the NESHAP limit. Radiological monitoring of animals shows no notable uptake of radionuclides in deer and no ecologically appreciable quantities of plutonium or americium in small animals (META/Berger 1995).

4.2.10 Savannah River Site (SRS)

SRS is located approximately 20 kilometers (12 miles) south of Aiken, South Carolina, bordering the State of Georgia at the Savannah River. DOE activities conducted at SRS involve tritium recycling, support for the nation's space program missions, storage of plutonium on an interim basis, processing of backlog targets and spent nuclear fuel, waste management, and research and development (DOE 1995g).

Land use at SRS, which comprises 80,200 hectares (198,200 acres), is generally categorized as forest, water, or developed facility locations. A total of 77,400 hectares (191,300 acres) of SRS are undeveloped, of which 72 percent are forested. A majority of the woodlands, comprising 53 percent of the total site, are in revenue producing, managed timber production. DOE designated the entire SRS as a NERP, which allows the scientific study of the cypress swamp, southeastern pine, and hardwood forest ecosystems (DOE 1995g).

On-site wells provide an average of 6.1 million liters (1.6 million gallons) of water per day. The capacity of the system is 19 million liters (5 million gallons) per day. Both on-site and public supply sources provide electrical power. The existing site load is 130 megawatts (META/Berger 1995).

SRS is located near the center of the Augusta-Aiken Interstate Air Quality Control Region. The EPA classifies the areas within SRS and its surrounding counties as attainment areas with respect to the NAAQS for criteria pollutants. There are no known PSD Class I areas in the vicinity of SRS (DOE 1995g).

The SRS region is in a temperate climate with short, mild winters and long, humid summers. The average annual temperature is 19 degrees Celsius (66 degrees Fahrenheit); average daily temperatures vary from 3 degrees Celsius (38 degrees Fahrenheit) in January to 33 degrees Celsius (91 degrees Fahrenheit) in July. The average annual precipitation is 126 centimeters (50 inches) (DOE 1995g). Prevailing winds at SRS are from the southwest through west-northwest and from the northwest and east-northeast. The average annual wind speed is 5.7 meters per second (12.8 miles per hour) (DOE 1995g).

SRS is located in the Aiken Plateau portion of the Upper Atlantic Coastal Plain east of the Fall Line, a major physiographic and structural feature that separates the Piedmont from the Coastal Plain, in southeastern South Carolina. The soils at the site are mainly sandy and sandy loams. The site lies within a Seismic Zone 2 and is in an area where earthquakes capable of producing structural damage are not likely to occur. Probabilistic seismic hazard curves were developed for all DOE sites in the 1980s, and the results for SRS indicated that a peak acceleration of 0.19 gravity was associated with a probability of 2×10^{-4} per year (5,000-year return period). Since 1985, only three earthquakes, all of Richter magnitude 3.0 or less, have occurred in the immediate area of SRS (DOE 1995g).

The primary surface water feature is the Savannah River, which borders the site for approximately 32 kilometers (20 miles) to the southwest. There are six major streams that flow through SRS into the Savannah River, and approximately 190 Carolina bays scattered throughout the site. Carolina bays are naturally occurring land depressions that can hold water. The Savannah River and on-site streams are classified as fresh water suitable for primary and secondary contact recreation, as a source for drinking water supply following conventional treatment, fishing, and industrial and agricultural uses (DOE 1995g).

The most shallow aquifer at SRS is commonly referred to as the water table. Below the water table is the Congaree aquifer, and below it is the Cretaceous aquifer. Although there are variations, groundwater in the Cretaceous aquifer discharges predominantly along the Savannah River. The Cretaceous aquifer is an abundant and important water resource for the SRS region. Some of the local cities, such as Aiken, also obtain groundwater from the Cretaceous, but most of the rural population in the SRS region gets its water from the Congaree or water table. Groundwater quality

ranges from excellent (soft and slightly acidic) to poor (exceeding EPA drinking water standards for several constituents) in the vicinity of some waste sites. The Cretaceous aquifer is generally unaffected except for a relatively small portion of the site near existing waste treatment, storage, and disposal facilities that is contaminated with trichloroethylene. The Congaree aquifer is contaminated with trichloroethylene over a relatively small portion of the site in the northeast part of SRS and low levels of tritium in the General Separation areas. The water table is contaminated with solvents, metals, or low levels of radionuclides at several waste sites and facilities (DOE 1995g). SRS is included on the CERCLA National Priorities List.

There have been five major plant communities identified at SRS. The loblolly-longleaf-slash pine community is the dominant community covering approximately 65 percent of the site. Swamp forests and bottomland hardwood forests are found along the Savannah River. SRS supports a diverse and abundant wildlife community, including 43 amphibian, 58 reptile, 213 bird, and 54 mammal species. SRS contains approximately 19,850 hectares (49,030 acres) of wetlands, most of which are associated with floodplains, streams, and impoundments. Sixty-one federal- and state-listed threatened, endangered, and other special status species have been identified at SRS. There is potential habitat in some areas for the Red Cockaded Woodpecker (*Dendrocopus borealis*).

More than 60 percent of SRS has received some level of cultural resources evaluation. More than 800 prehistoric sites have been identified, although fewer than 8 percent have been evaluated for eligibility to the NRHP. Approximately 400 historic sites have been identified within SRS, ten of which are eligible for the NRHP. Literature reviews and consultations with Native American representatives reveal that there are some concerns related to the American Indian Religious Freedom Act within the central Savannah River valley.

Four counties in which 87 percent of all SRS employees reside compose the economic ROI. SRS currently employs approximately 16,300 persons (4.6 percent of the total regional economic area employment) (DOE 1995g). The total population in the ROI in 1990 was 460,028 with approximately 37 percent minority and 14 percent below poverty level. The ROI unemployment rate was 8.4 percent in 1991 (META/Berger 1995).

Interstate-20 is located approximately 29 kilometers (18 miles) northeast of SRS, providing the nearest interstate access to the site. State Routes 19, 64, and 125 are used by 40, 10, and 50 percent of the SRS commuters, respectively. SRS is served by more than 200 miles of primary roads on-site. Railroad service is also available through SRS (DOE 1995g).

The annual radiation dose to the population residing within 80 kilometers (50 miles) of the site from normal accident-free operations during 1994 would result in 8×10^{-3} LCFs. The population within this area was 620,000. The annual dose from airborne radionuclides to the MEI during 1994 would result in a 8×10^{-8} probability of an LCF. The corresponding dose is below the NESHAP limit.

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CHAPTER 5
ENVIRONMENTAL IMPACTS

This chapter presents the results of environmental impact analyses for the Proposed Action, the three action alternatives, and the two no action alternatives. Environmental impacts of each alternative are discussed separately.

The environmental impacts that could result should the Proposed Action or any of the alternatives be implemented have been divided into four categories:

- Those impacts that would occur at the treatment sites due to the treatment and storage of transuranic (TRU) waste (for all alternatives), those that would occur both during and after long-term storage (for all alternatives except the Proposed Action), and those due to transporting the waste for treatment (for all alternatives except No Action Alternative 2)

- Those impacts that would occur due to transporting TRU waste from the treatment sites to the Waste Isolation Pilot Plant (WIPP) (except for the two no action alternatives)

- Those impacts that would occur due to waste handling, disposal, and decommissioning at WIPP (for the Proposed Action and all of the action alternatives) and the decommissioning of WIPP (for the no action alternatives)

- Those impacts that would occur due to releases associated with closure of the repository, long-term disposal of the waste, and any retrieval and recovery of the waste (for the Proposed Action and action alternatives)

As noted in Chapter 1, the Record of Decision (ROD) that followed the *Final Supplement Environmental Impact Statement for the Waste Isolation Pilot Plant* (SEIS-I) (DOE 1990) stated that an analysis of the impacts of processing and handling TRU waste at the treatment sites would be conducted. The U.S. Department of Energy (DOE or the Department) has analyzed TRU waste processing and handling at its sites in the *Final Waste Management Programmatic Environmental Impact Statement* (WM PEIS) (DOE 1997). Because estimates of TRU waste volumes and radionuclide and hazardous chemical inventories have been updated since those used in the WM PEIS were developed (as reported in Appendix A), a revised analysis of those impacts is included in this chapter. The following points highlight how impacts due to treatment and handling were assessed for this supplemental environmental impact statement (SEIS-II).

- WM PEIS annual air quality impacts at the treatment sites have been incorporated by reference and summarized in SEIS-II. The impacts assessed in the WM PEIS were considered appropriate because the facilities assumed in the WM PEIS analysis would be the same number, type, and size as those assumed in SEIS-II. Though additional waste would be treated under some SEIS-II alternatives, the assumed treatment period is 35 years rather than the 10 years assumed in the WM PEIS; therefore, the annual rate of treatment and annual air impacts would not increase.

- Estimated total life-cycle costs for the treatment and transportation of TRU waste to potential consolidation sites used the methods developed for the cost analysis in the WM PEIS. Total life-cycle costs for TRU waste treatment for the entire DOE Complex have been reported. Additional details on the estimated costs and the methods used for estimating these costs are presented in Appendix D.

- The impacts that may occur due to transporting TRU waste from the treatment sites to WIPP are based upon the alternatives presented in the WM PEIS. The impacts were based upon the updated TRU waste volumes and radionuclide and hazardous chemical inventories reported in SEIS-II. Similarly, the impacts due to waste handling at WIPP also were based on these updated inventories. Details on the transportation analyses are presented in Appendix E.

- Industrial safety impacts due to treatment facility construction and operation were adjusted from those in the WM PEIS. The adjustments were based upon the increased construction and operations time estimated under the SEIS-II alternatives. The WM PEIS anticipated 10 years of planning and construction followed by 10 years of operations. SEIS-II analyses anticipated 35 years of operation for all alternatives. Those SEIS-II alternatives requiring shred and grout facilities or thermal treatment facilities also included a 12-year planning and construction period.

- Impacts to water resources and infrastructure (including wastewater, power, and roadways) may occur due to construction and operation of treatment and storage facilities. The potential impacts presented in the WM PEIS are incorporated by reference and summarized in the following sections. No annual increases to these potential impacts would be anticipated due to differences between the inventories used for the WM PEIS and SEIS-II. As decisions are made regarding the specific location of TRU waste treatment and storage facilities, site-specific National Environmental Policy Act (NEPA) reviews will be conducted, as appropriate.

- Impacts to ecological resources, land use, and cultural resources may occur due to construction and operation of treatment and storage facilities. The WM PEIS reported that "major impacts to the resources at the sites are unlikely" because they can be avoided. The treatment facilities would need less than 1 percent of available land at proposed treatment site locations. Also, as decisions are made regarding the location of TRU waste treatment and storage facilities, site-specific NEPA reviews will be conducted, as appropriate.

ENVIRONMENTAL ANALYSES

The potential environmental impacts presented throughout Chapter 5 rely on information gathered during extensive site characterization and experimental programs and on the various scientific and engineering analyses performed by DOE since investigation of the WIPP site began in the late 1970s. Analyses used throughout SEIS-II are designed to provide conservative estimates of the reasonably foreseeable impacts that may occur.

Where appropriate, conservative assumptions are employed; thus, the analyses have a tendency to overestimate impacts. Typically, the analytical methods employed are examined in the appendices. A summary of the reasonably foreseeable impacts and key assumptions considered are presented throughout this chapter.

COMPARING ALTERNATIVES

When comparing the impacts and costs of SEIS-II alternatives, it is important to recognize that disposal at WIPP would isolate waste for more than 10,000 years, while continuing storage in facilities would isolate waste for a maximum of 100 years before reconstruction or disposal (at WIPP or some other location) would be necessary. SEIS-II alternatives that would dispose of the largest amount of waste at WIPP would isolate more waste for a longer period of time than those alternatives that would dispose of less waste while storing the rest. The differences in the degree of waste isolation that DOE would achieve for a given set of costs and impacts should be considered by the reader when comparing alternatives because these differences, in some cases, are noteworthy.

For purposes of comparison, each alternative presents the impacts that potentially would occur (1) at treatment sites due to waste treatment and storage, (2) as a result of transporting TRU waste among the sites and to WIPP for disposal, (3) at WIPP from TRU waste handling and disposal operations, and (4) as a result of long-term releases from the closed repository or storage facilities.

As appropriate, potential environmental impacts are further identified as either resulting from the Basic Inventory or the Additional Inventory, each of which is composed of contact-handled (CH) TRU waste and remote-handled (RH) TRU waste (see Table 3-18 for a summary of the results).

- Human health impacts from TRU waste treatment were adjusted from the impacts presented in the WM PEIS. Additional details on the methods used for adjusting these results are presented in Appendix B.

Potential environmental impacts from waste treatment, waste storage, transportation, disposal, and releases following WIPP closure are presented below for the Basic Inventory and the Additional Inventory, each of which includes contact-handled (CH)-TRU and remote-handled (RH)-TRU waste. These results are presented to facilitate comparisons within and between alternatives (see Table 3-18 for a summary of the results). Sums and products of numbers in this chapter may not appear consistent because of rounding.

5.1 IMPACTS OF THE PROPOSED ACTION (PREFERRED ALTERNATIVE, RESERVING RAIL TRANSPORTATION FOR FUTURE CONSIDERATION)

The environmental impacts associated with implementation of the Proposed Action are detailed within this section. The Proposed Action would continue with the phased development of WIPP by disposing of TRU waste at the facility. Under the Proposed Action, WIPP would accept only newly generated defense TRU waste and that post-1970, defense TRU waste in retrievable storage. Throughout this document this inventory is referred to as the Basic Inventory. Waste would be treated to meet the Waste Acceptance Criteria (WAC); for purposes of analysis, the current planning-basis WAC were used (DOE 1996c). Any consolidation under the Proposed Action would occur in the manner described in the ROD to be issued for the WM PEIS. For the purposes of analysis in SEIS-II, consolidation was assumed at 10 sites for CH-TRU waste and four sites for RH-TRU; the sites are shown in Figure 3-1 in Chapter 3. (The impacts should consolidation not occur, or limited consolidation as in the WM PEIS preferred alternative occur, are presented in a text box at the end of Section 5.1). Treatment at the sites and disposal at WIPP would occur over a 35-year operating period, through the year 2033. A more detailed description of the Proposed Action is given in Section 3.1.

5.1.1 Land Use and Management

DOE found in the WM PEIS that the facilities needed to manage and treat TRU waste under the Proposed Action would require less than 1 percent of the land available for such activities at each proposed treatment site. In calculating the percentage, DOE removed from consideration any acreage with known cultural resource areas, sensitive habitats (including wetlands and wildlife management areas), prohibitive topographic features, and surface water. As a result, the WM PEIS states that DOE would "have considerable flexibility in locating those facilities and impacts to on-site land use would probably be minimal." The Department would be able to minimize impacts to on-site land use and avoid conflicts with any off-site land use plans (DOE 1997). The Department also would locate treatment facilities such that sensitive or inappropriate areas would be avoided. These sensitive or inappropriate areas would include flood plains, wetlands, known cultural resource areas, and the habitats of threatened or endangered species.

No substantial changes in this finding due to differences between the WM PEIS and SEIS-II were determined. The WM PEIS also assumed that the facilities would be large enough to treat all of the TRU waste in 10 years (for consistency of analysis across waste types); for SEIS-II, it was assumed that treatment would be completed within 35 years, as the waste is generated. Although the SEIS-II operations time would be three and one-half times longer than that anticipated under the WM PEIS, the size and number of the treatment facilities needed for this SEIS-II alternative would be the same as those analyzed for the WM PEIS. The specific location of treatment and waste management facilities within each site would be selected following additional site-wide or project-level NEPA reviews (for an explanation of tiered NEPA reviews, see Appendix B).

Under the Proposed Action, DOE would continue to occupy the land transferred to it by the WIPP Land Withdrawal Act (LWA). DOE would exercise its easements on land outside the WIPP withdrawal area for such uses as groundwater surveillance pads, signs, and transportation and utility corridors. The total aboveground disturbed area is estimated to be 20 hectares (50 acres), equal to the area of the current aboveground facilities. Additional construction at WIPP would be limited to its underground disposal area. During the closure period when a berm and permanent markers would be constructed over the underground disposal area, a total of 70 hectares (173 acres) would be disturbed.

Local WIPP land use includes grazing, recreation, and mining (Section 4.1.1). Currently, an area of 120 hectares (300 acres) is fenced and posted to prevent grazing, trespassing, or other uses. Other grazing areas within the withdrawn area are managed pursuant to the *Waste Isolation Pilot Plant Land Management Plan* (DOE 1996a). Access to a 590-hectare (1,454-acre) area of the WIPP site (the "Off Limits Area") is currently restricted to grazing (see Figure 4-2). Other areas are open to the public; however, various resources in the withdrawn area are protected. The LWA prohibits any surface or subsurface mining unrelated to the WIPP project, with the exception of two hydrocarbon leases. No activity is occurring under these leases, and the Department may acquire these leases in the future. The Proposed Action would continue these restrictions and land use management practices throughout the disposal and post-closure periods.

5.1.2 Air Quality

For TRU waste treatment, the only criteria pollutant postulated to exceed 10 percent of the applicable annual regulatory standard during operation of treatment facilities would be carbon

monoxide (CO) at the Rocky Flats Environmental Technology Site (RFETS) (17 percent) (see Appendix C). RFETS, Lawrence Livermore National Laboratory (LLNL), Nevada Test Site (NTS), and Argonne National Laboratory-East (ANL-E) are in nonattainment areas for some of the pollutants. In those areas where air pollution standards are not met (nonattainment areas), activities that introduce new sources of emissions are regulated under the General Conformity Rule. In areas where air pollution standards are met (attainment areas), regulations for the Prevention of Significant Deterioration (PSD) of ambient air quality apply. In both cases, a permit is required for sources that will result in emissions equal to or greater than the limits set by pertinent regulations. No radiological, hazardous, or toxic air pollutants would exceed 10 percent of the applicable regulatory standard during normal accident-free treatment (DOE 1997). Particulate matter less than or equal to 10 microns in diameter (PM_{10}) levels may increase during construction.

For SEIS-II, air quality impacts from operation of WIPP under the Proposed Action have been updated from those contained in Section 9.4.5 of the *Final Environmental Impact Statement for the Waste Isolation Pilot Plant* (FEIS) (DOE 1980) and referenced in SEIS-I (DOE 1990). SEIS-II air quality analyses also include information on the salt pile fugitive dust emissions (Tillman 1988b), emissions of particulates from the ventilation system (Tillman 1988a) not included in SEIS-I, and reflect fewer salt pile releases from bulldozer activity and fewer emissions from mining and support equipment because they would be smaller, electric, or would be used less often (Hollen 1996) than reported in the FEIS or SEIS-I.

The four criteria pollutants considered at WIPP were nitrogen dioxide (NO_2), sulfur dioxide (SO_2), CO, and PM_{10}. Volatile organic compounds (VOC), as ozone precursors, were also considered. Potential impacts were determined using the methods described in Appendix C. There would be only negligible releases of two other criteria pollutants, ozone and lead, under the Proposed Action. Principal emission sources of particulates from operation of WIPP under the Proposed Action are (1) exhaust from underground mining, (2) surface salt handling, (3) wind erosion of the salt pile, and (4) fuel combustion from two back-up diesel generators and mining and support equipment. Fuel combustion would be the principal source of NO_2, SO_2, and CO.

Estimates of criteria pollutant air quality impacts from WIPP disposal operations under the Proposed Action are provided in Table 5-1. WIPP would remain an attainment area for all criteria pollutants, and there would be no impact to nearby national parks (Carlsbad Caverns and Guadalupe Mountains) which are Class I attainment areas. Increases in annual concentrations of each analyzed pollutant would be small (less than 2 percent of the regulatory limit). Some 24-hour impacts could be, on a short-term basis, as high as 65 percent of regulatory limits (for NO_2) due primarily to use of backup generators. These estimates represent an upper limit to the 24-hour impacts owing to the conservative assumptions used in the modeling. These conservative assumptions included that low-velocity wind would blow directly at a receptor under stable atmospheric conditions, thus minimizing dispersion and maximizing concentrations. Calculated VOC releases (an ozone precursor) were compared to the New Mexico PSD regulation (Air Quality Control Regulation [AQCR] 707), a major source screening criteria for ozone (40 tons per year). Calculated VOC emissions (an ozone precursor) from waste disposed of in WIPP would not exceed 2 percent of this level. Radionuclide releases would be less than 0.1 percent of the limit specified in the National Emissions Standard for Hazardous Air Pollutants (NESHAP) (40 Code of Federal Regulations [CFR] 61, Subpart H).

Table 5-1
Impacts on Air Quality at WIPP for the Proposed Action

Criteria Pollutant	Averaging Time	Concentration at Maximally Impacted Point of Unrestricted Public Access (μg per cubic meter)	Regulatory Limit (μg/cubic meter)	Percent of Regulatory Limit
PM_{10}	Annual	0.67	50 [a]	1.3
	24-hour	85	150 [a]	57
NO_2	Annual	0.28	84 [b]	0.3
	24-hour	110	168 [b]	65
SO_2	Annual	0.02	47 [b]	0.05
	24-hour	8.5	234 [b]	3.6
	3-hour	77	1,170 [c]	6.6
CO	8-hour	110	8,900 [b]	1.3
	1-hour	410	13,400 [b]	3.1

[a] National primary ambient air quality standard (40 CFR Part 50).
[b] New Mexico ambient air quality standard (AQCR 201) corrected for altitude.
[c] National secondary ambient air quality standard (40 CFR Part 50) corrected for altitude.

The plans for decommissioning WIPP under the Proposed Action are described in Section 3.1.3.5. Potential air quality impacts could result from the construction of berms around and permanent markers in the surface area overlying the underground disposal area, dismantling all the aboveground structures on the site, and reclaiming the salt pile. Specifically, air quality impacts would be the result of fugitive dust and emissions from heavy-duty construction equipment typical of a large construction project. Reclaimed salt may be used to either close the shafts or as a base for the berm. Excess salt may be sold for other purposes and transported off-site by private carrier. Decommissioning would produce temporary increases in dust and other criteria pollutants but no substantial long-term impacts.

5.1.3 Biological Resources

Analyses conducted during the WM PEIS determined that construction and operation of TRU waste treatment facilities should not have major adverse effects on populations of nonsensitive plant and animal species for two reasons: (1) no more than 11 hectares (28 acres) would be disturbed at any site, and (2) the habitats for these species are well established regionally near the proposed treatment sites. Site activities are not expected to affect ecosystem balance or biodiversity. Also, because so little land would be required for the waste management and treatment facilities, DOE would be able to locate the new facilities to avoid impacts to sensitive habitat areas (see Section 5.1.1).

Threatened and endangered species appear at all of the proposed treatment sites and could potentially be impacted; however, whether there would be impacts depends on the actual location of the facility at a particular site. Such species and their critical habitats would be avoided, and appropriate consultation, monitoring, and mitigation measures would be undertaken. Site selection would be conducted following site-wide or project-level NEPA review during which such impacts would be assessed. The WM PEIS analyses also determined that terrestrial wildlife species were unlikely to be affected by airborne emissions from waste management or treatment facilities, or from spills of TRU waste into aquatic environments due to traffic accidents. These findings of the

WM PEIS also are applicable to SEIS-II, though a larger inventory would be treated under the Proposed Action than that considered for the WM PEIS because the size and number of facilities would be the same.

Federally listed, threatened and endangered, and state-listed species occur in Eddy and Lea counties and potentially at WIPP, although DOE has not observed threatened, endangered, or proposed species or critical habitats at the WIPP site during surveys conducted for recent biennial environmental compliance reports. DOE recently completed a biological survey, during which no threatened, endangered, or state-listed species were identified at the WIPP site, and the results are being shared with the U.S. Fish and Wildlife Service.

At WIPP, vegetation-monitoring data from 1989 through 1993 were consistent with those reported in SEIS-I (DOE 1990), which indicated no salt-related stress in vegetation except for that directly near the salt pile. At the salt pile, based on past observations, increased shrub cover near the salt cuttings is anticipated due to colonization by saline-tolerant species such as the fourwing saltbush (*Atriplex canescens*) (DOE 1995c). Throughout the WIPP site, however, no change in foliage was occurring at the time of SEIS-I, and recent environmental reports indicate that this is still the case (DOE 1991, 1992, 1993, 1994b, and 1995c). SEIS-I also reported a salt buildup in the soil below 75 centimeters (30 inches) but stated that it was not affecting the vegetation and that the buildup was not expected to continue. During disposal operations, the salt pile is anticipated to stabilize as a 12-hectare (30-acre) working pile, which would not affect the ecosystem balance. Salt tolerant plant species would replace less saline-tolerant species such as the black grama grass (*Bouteloua eriopoda*) and are not expected to affect site ecosystem balance or biodiversity (DOE 1994b).

Over 10 years of avian survey data at WIPP (from 1984 through 1994) have revealed no discernible impacts on densities and distributions of breeding birds due to activities in the areas adjacent to the surface facilities. The Cooperative Raptor Research and Management Program has reported no adverse effects to raptors from WIPP activities. In addition, no adverse effects to small mammals from WIPP operations have been reported (DOE 1995c). Negligible impact to plant and animal communities near the WIPP site would be expected because almost all of the proposed operations would be conducted underground or in areas already developed.

Decommissioning and closure of the WIPP site would result in the dismantling of all aboveground structures and reclamation of the area. These activities would affect approximately 70 hectares (175 acres), resulting in the loss of much of the plant community and avian and small mammal habitats within and near the area. DOE would return decommissioned lands used in the operation of WIPP to a stable ecological condition and maintain or enhance the ecological condition of wildlife habitat within the WIPP Land Withdrawal Area (DOE 1996a).

5.1.4 Cultural Resources

Because cultural resources at many of the treatment sites are eligible or potentially eligible for the National Register of Historic Places (NRHP), construction and operation of TRU waste management and treatment facilities could have an adverse effect. Site-level cultural resource surveys would be conducted and protection measures established, where necessary, when specific facility locations are proposed (DOE 1997). These surveys would be part of site-wide or project-level NEPA reviews. Any Native American sacred sites and burial grounds would be avoided and appropriate consultation would be undertaken.

At WIPP, disposal surface activities and salt pile maintenance would take place within already disturbed areas of the Property Protection Area. Because no new construction of surface features would occur, impacts to cultural resource properties are not anticipated as part of the shipping, waste handling, or emplacement operations. Previous research of the site cultural resources has identified and evaluated individual properties and mitigated, as necessary, potential impacts from the construction of surface features in the Property Protection Area. No Native American sacred sites or burial grounds have been identified to date.

Activities undertaken in conjunction with closure and decommissioning under the Proposed Action, may have potentially adverse impacts on cultural resources, depending on the ultimate design of the permanent marking system and the berm. Two prehistoric archaeological sites, LA33179 and LA33180, are located within the proposed surface closure area. Both sites were evaluated as being potentially eligible for inclusion on the NRHP (DOE 1995c). Site LA33179 was subjected to surface collection of artifacts and subsurface testing in 1981 (DOE 1996a). Site LA33180 appears to be partially buried and may require testing and mitigation activities if important subsurface cultural deposits are present.

Measures for ensuring protection of known archaeological and historic resources, or others that may be inadvertently discovered during ground-disturbing activities, are discussed in the *Waste Isolation Pilot Plant Land Management Plan* (DOE 1996a). These measures include identifying, inventorying, evaluating, and treating cultural resources under the National Historic Preservation Act of 1966. DOE will avoid, to the maximum extent possible, sites found eligible for inclusion in the NRHP. Where avoidance is not possible, mitigation measures will be developed under the recently signed Joint Powers Agreement with the State of New Mexico.

5.1.5 Noise

According to the WM PEIS, treatment facilities would probably be placed at industrial-type sites along high traffic volume corridors; therefore, treatment should not substantially increase ambient noise levels. Still, the WM PEIS notes that sensitive receptors may be impacted. Site-specific noise impacts will be assessed in a site-wide or project-specific NEPA document when siting treatment facilities. Noise impacts due to waste transportation to or from the treatment sites would be less than noise levels near the WIPP site (discussed below). Under this alternative, all waste would travel to WIPP but only a portion of the waste would travel to or from each treatment facility.

Noise impacts at the WIPP site were initially evaluated in the FEIS (DOE 1980) which provided a qualitative evaluation of operational impacts that remains accurate for SEIS-II. The FEIS determined that an overall sound pressure level of 50 decibels might occur 120 meters (400 feet) from the Waste Handling Building due to normal operations. The noise should not be heard at the nearest residence. The FEIS also indicated that should all of WIPP's equipment be operated at once or its emergency generators tested simultaneously, the noise level may increase. However, the FEIS also states that the levels would typically be within acceptable limits as established by the U.S. Department of Housing and Urban Development (DOE 1980).

Under the Proposed Action, all truck transportation of TRU waste would travel through Carlsbad, New Mexico (see figures in Appendix E for routes). Waste from all of the sites east of the Mississippi River would arrive from the south on U.S. 285. Waste from all other sites would come from the north on U.S. 285, passing through Vaughn, Roswell, and Artesia, New Mexico,

prior to arriving at Carlsbad. Trucks would arrive at random times throughout two WIPP working shifts. Impacts were estimated based on a maximum throughput of 50 TRUPACT-IIs and eight RH-72Bs per week, corresponding to a maximum of eight trucks per day. Data from the New Mexico State Highway and Transportation Department (NMSH&TD 1997) showed annual average daily traffic at the intersection of Canal and Greene streets in Carlsbad to be approximately 7,700 in 1994. In 1996, estimated daily traffic was approximately 7,900. The increase in noise associated with the Proposed Action's additional truck traffic would be negligible compared to the background noise level associated with existing automobile and truck traffic in Carlsbad and along the transportation corridors.

5.1.6 Water Resources and Infrastructure

Negligible impacts on water resources are expected at the treatment sites due to the Proposed Action. The WM PEIS assessed water availability issues by identifying whether water needs during construction and operation of treatment facilities would increase by more than 1 percent at the DOE facilities proposed as treatment locations. Under this alternative, only Idaho National Engineering and Environmental Laboratory (INEEL), LLNL, and RFETS would have such increases. The increases would be 1.2, 2.8, and 2.1 percent, respectively, and could be accommodated by existing water supplies.

Although no off-site annual infrastructure impacts would be expected at the treatment sites, proposed TRU waste activities would affect on-site activities. The affected infrastructure elements analyzed were on-site transportation and the capacity of on-site water, power, and wastewater systems. Water and power were evaluated for both construction and operations; wastewater treatment was evaluated only for operations because construction wastewater was assumed to be negligible (DOE 1997).

Under the Proposed Action, only the Hanford Site (Hanford) would show an increase in on-site demand for wastewater treatment that would exceed 5 percent of current demand (5.9 percent). Major impacts to water resources at the sites would be unlikely for treatment of TRU waste (DOE 1997).

Minor impacts to the on-site transportation infrastructure under the Proposed Action might occur. These impacts would be the result of an increase in on-site employment of 6 percent at Hanford and INEEL and 7 percent at Los Alamos National Laboratory (LANL). Impacts to the off-site transportation infrastructure are not anticipated because population increases would not exceed five percent (DOE 1997).

Disposal operations at WIPP would result in increased vehicle traffic from both the site work force and waste transport vehicles, but no new construction of roads or rail lines by DOE for waste transport is anticipated. Negligible annual infrastructure impacts would be expected at WIPP under the Proposed Action. Existing water supply and sewer capabilities, and existing and planned power and roadway resources would be able to accommodate proposed disposal operations.

5.1.7 Socioeconomics

Estimated life-cycle costs and potential socioeconomic impacts under the Proposed Action are presented in the following subsections.

5.1.7.1 Life-Cycle Costs

Life-cycle costs under the Proposed Action are presented in Table 5-2 for three areas: waste treatment facilities, waste transportation, and WIPP disposal operations. Waste treatment facility costs include construction, operations and maintenance (O&M), and decontamination and decommissioning (D&D) at the TRU waste treatment sites. These sites would process, treat, and package waste over a period of 35 years to meet planning-basis WAC. The waste treatment facility costs, excluding storage costs for any excess RH-TRU waste, are estimated to be $11.83 billion, or an annualized cost of $340 million (in 1994 dollars). The waste transport costs include the costs of consolidating waste volumes at the 10 sites and then shipping the treated volumes to WIPP for disposal over the 35-year period. The waste transport costs are estimated to be $1.59 billion, or an average of $45 million per year. Finally, the WIPP site life-cycle costs are projected to be $5.3 billion, or $150 million per year. The WIPP site life-cycle costs cover a 35-year waste emplacement period followed by a 10-year decommissioning period. The total life-cycle cost of the Proposed Action is $19.03 billion or $10.13 billion when discounted. More details regarding life-cycle costs may be found in Appendix D. The cost impacts would be essentially the same should waste not be consolidated.

DOE is restricted by the Consultation and Cooperation Agreement (C&C) to disposal of a maximum of 7,080 cubic meters (250,000 cubic feet) of RH-TRU waste at WIPP. Thus, there is approximately 43,000 cubic meters (1,530,000 cubic feet) of RH-TRU waste under the Proposed Action that could not be disposed of at WIPP and that would require long-term storage at the treatment facilities.[1] Based on WM PEIS storage cost estimates presented in the site data tables for Hanford and Oak Ridge National Laboratory (ORNL), the additional life-cycle cost of storing the excess RH-TRU waste for 35 years would be approximately $310 million (in 1994 dollars) or $170 million when discounted. (These costs are included in the total life cycle costs for the Proposed Action.) The need for this type of storage is not necessary under the action alternatives because the action alternatives assume that all TRU waste would be disposed of at WIPP.

Table 5-2
Life-Cycle Costs for the Proposed Action
(in millions of 1994 dollars) [a]

Cost Information	Basic Inventory CH-TRU Waste	Basic Inventory RH-TRU Waste	Basic Inventory CH-TRU and RH-TRU Waste	Discounted Basic Inventory CH-TRU and RH-TRU Waste
Treatment Facilities	8,850	2,980	11,830	6,560
Transport by Truck	1,260	330	1,590	880
Disposal at WIPP	4,200	1,100	5,300	2,500
Excess RH-TRU Waste Storage	---	310	310	170
Total Life-Cycle Cost	14,310	4,720	19,030	10,130

[a] The methods and assumptions used to estimate the various cost components are described in Appendix D. Totals may differ due to rounding.

[1] The most recent volume estimates for RH-TRU waste are much lower than those used in SEIS-II. Those estimates indicate all currently stored post-1970, defense RH-TRU waste and waste to be generated could be disposed of in WIPP. See Appendix J.

LIFE-CYCLE COSTS AND DISCOUNTING

A life-cycle is the entire life of a project from conceptual design to completion (through decommissioning). For these analyses, life-cycle costs at WIPP comprise waste management and disposal costs at the WIPP facility from the beginning of the disposal phase through decommissioning. At the treatment facilities, the life-cycle costs include all activities from conceptual design through closure. Total life-cycle costs also include transportation costs.

To allow for more consistent program evaluations relative to the various WM PEIS estimates, the SEIS-II estimates are presented in 1994 dollars. Moreover, to allow for more consistent program evaluations relative to the various SEIS-II alternatives the life-cycle cost estimates are also presented in present value terms. The practice of discounting future costs gives more weight to money that is spent in the near future compared to money spent in the distant future. The justification for discounting future dollar values stems from the desire to know the equivalent, present-day values. For example, if $100,000 of expenses are anticipated during the 50th year of a project and the discount value is 5 percent per year, the equivalent present-day value would be $8,208.50, assuming that the $8,208.50 was reinvested continuously for 50 years with 5 percent compound interest. Thus, the process of discounting future dollar values reflects the common-sense understanding that money at the present time is worth more than money at a future time, as it takes only $8,208.50 today to produce $100,000 in 50 years.

The present value of the life-cycle costs was estimated using a 1996, inflation-adjusted annual discount rate of 4.1 percent. Economic impact estimates are based on life-cycle cost estimates and are not discounted further. These estimates represent annual effects over the life of the alternative.

5.1.7.2 Economic Impacts

TRU waste treatment activities would support direct, indirect, and induced jobs. The Proposed Action would support approximately 11,900 jobs in the regions of influence (ROI) of the 10 major treatment sites (ANL-E, Hanford, INEEL, LANL, LLNL, the Mound Plant [Mound], NTS, ORNL, RFETS, Savannah River Site [SRS]).

Estimates of the impacts of the Proposed Action on employment, income, and the production of goods and services within the WIPP ROI are presented in Table 5-3. These regional impacts are estimated using an average project budget of $180 million per year over a 35-year period of waste disposal operations. Over this period, the WIPP facility would remain a stable federal employer in the ROI economy, providing direct employment for 1,095 project personnel annually. The operation of WIPP (from 1998 through 2033) would annually support 2,443 indirect and induced jobs in the ROI work force. The estimates of total WIPP-induced employment within the ROI reflect the sum of these direct, indirect, and induced employment levels. In percentage terms, the Proposed Action could result in supporting as much as 7.9 percent of all employment in the ROI. Appendix D provides details regarding these estimations and impacts specific to the local Carlsbad economy.

Table 5-3
Economic Impacts Within the WIPP ROI for the Proposed Action

Economic Effects	Total Output of Goods and Services (in millions of 1994 dollars)	Total Employment (Full- and Part-Time Jobs)	Total Labor Income (in millions of 1994 dollars)	Carlsbad Output of Goods and Services (in millions of 1994 dollars)	Carlsbad Employment (Full- and Part-Time Jobs)	Carlsbad Labor Income (in millions of 1994 dollars)
Direct – Annual	113	1,095	52	95	979	46
Indirect & Induced – Annual	204	2,443	75	172	2,185	67
Total – Annual	317	3,538	126	267	3,164	113
Total - Operations (35 years)	11,079	123,830 [a]	4,411	9,345	110,740 [a]	3,955

[a] Job-years (number of annual jobs supported multiplied by the number of years in the project).

Because the projected annual budget is close to levels observed from 1988 to 1996, the Proposed Action is not expected to result in additional use of government-provided goods or services (schools, police, fire protection, and health protection) nor should it require major capital investments in public infrastructure within the ROI. For this same reason, the Proposed Action is not expected to impact the local real estate market or result in major changes in the work force population. (Discussion of the economic impacts resulting from WIPP's closure is in the discussion of No Action Alternative 1.)

5.1.8 Transportation

This section examines the potential environmental impacts of transporting TRU waste in accordance with the consolidation, treatment, and disposal methods described for the Proposed Action in Chapter 3. The results shown here update the results of SEIS-I. SEIS-II uses essentially the same methods for assessing transportation impacts as were used for SEIS-I. The major differences between the two sets of analyses are the following:

- SEIS-II analyses use 1990 Census data for population impacts. These data were not available for SEIS-I.

- SEIS-II analyses include transportation of TRU waste from several sites that are storing small quantities of the waste. Transportation of this waste was not considered in SEIS-I.

- SEIS-II analyses use a larger TRU waste inventory.

- SEIS-II analyses consider three transportation risk assessments prepared since SEIS-I was published. They are the *Comparative Study of WIPP Transportation Alternatives* (DOE 1994a), the WM PEIS (DOE 1997), and the *Engineered Alternatives Cost/Benefit Study Final Report* (DOE 1995d).

In assessing the impacts of transporting TRU waste, several measures were used. The most fundamental of these was the number of traffic accidents, fatalities, and injuries likely to occur as a result of transportation unrelated to the waste type. Another impact assessed was that caused by vehicle emissions (diesel exhaust); this impact is termed pollution health effects. A third measure, termed accident-free radiological impacts, is associated with the external radiation present around a TRUPACT-II or RH-72B container as it is being shipped. The general public and transportation workers would be exposed to very low levels of radiation during shipment. The final measure is

associated with accidents that are severe enough to breach the waste packages and release some of the radioactive and hazardous material being shipped.

The first step in all of these analyses was to determine the highway routes that would be used for transporting waste to WIPP. All of the impacts are a function of route characteristics, the number of shipments via each route, and, for the accident risks, the accident environment associated with a particular mode of transportation and the behavior of the waste form and packaging in that accident environment. Therefore, a major focus of this section is to summarize important route characteristics, the waste shipment volumes using each route, and the impacts of potential accidents.

The following sections estimate the impacts of shipping TRU waste to WIPP. The first subsection is devoted to developing the data needed. It is followed by subsections devoted to analyzing the various transportation impacts associated with transporting waste. Each section also presents the impacts for transporting waste from sites with smaller quantities to the treatment sites. The results of the truck transportation analyses to WIPP were adjusted to account for the additional miles and shipments between these sites.

5.1.8.1 Route Characteristics and Shipment Projections

Under the Proposed Action, waste destined for WIPP would originate at 18 sites around the United States. Many of these sites have generated small quantities of TRU waste and are no longer generating waste. The waste present at these sites could be shipped to one of 10 sites with larger TRU waste volumes (see Chapter 3 for tables and maps detailing the consolidation). The number of CH-TRU and RH-TRU waste shipments from each of these 10 sites to WIPP under the Proposed Action are shown in Table 5-4. The number of TRU waste shipments is primarily dependent on limitations concerning weight, gas generation, plutonium-239 equivalent curies (PE-Ci), and thermal power limits that are incorporated into the planning-basis WAC. The methods used to determine the number of shipments are outlined in Appendix A.

Table 5-4
Number of Truck Shipments to WIPP for the Proposed Action [a]

Waste Treatment Site	CH-TRU Waste	RH-TRU Waste
Argonne National Laboratory-East	28	0
Hanford Site	13,666	3,178
Idaho National Engineering and Environmental Laboratory & Argonne National Laboratory-West	5,782	3,136
Lawrence Livermore National Laboratory	162	0
Los Alamos National Laboratory	5,009	367
Mound Plant	59	0
Nevada Test Site	86	0
Oak Ridge National Laboratory	251	1,276
Rocky Flats Environmental Technology Site	2,485	0
Savannah River Site	2,238	0
Total	**29,766**	**7,957**

[a] The number of shipments from sites with smaller quantities can be found in Appendix E. There would be 27 CH-TRU waste shipments and 958 RH-TRU waste shipments. Impacts from the transportation of TRU waste to the major treatment sites (see Appendix E) are small relative to impacts from shipment between the major treatment sites and WIPP.

The HIGHWAY code (Johnson et al. 1993) was used to estimate trip lengths from the 10 major treatment facilities to WIPP and to estimate the corresponding population density fractions along the routes. Built into the HIGHWAY code are the routes that were selected by the states and accepted by the Department of Transportation for the shipment of route-controlled quantities of radioactive materials. Not all shipments to WIPP will fall within the definition of a highway route-controlled quantity (HRCQ) (49 CFR Part 173.403(l)), DOE, as a matter of policy, has determined that all shipments, whether they are empty or full and whether or not they meet the definition of HRCQs, will use the U.S. Department of Transportation (DOT) preferred routes as defined in 49 CFR Part 397 Subpart D. Selected routes, shown in Appendix E, generally follow interstate highways. The major exception to this is New Mexico, where the state has selected U.S. Highway 285 as the primary northern route between Interstate-25 near Santa Fe, New Mexico, and WIPP, and the southern route between Interstate-20 at Pecos, Texas, and WIPP. Table 5-5 presents the total miles from the 10 major treatment sites to WIPP and the total miles along the route for rural, suburban, and urban population zones for potential shipments to WIPP under the Proposed Action.

Table 5-5
Mileage for Shipping TRU Waste by Truck to WIPP for the Proposed Action [a]

Origination Site	Total One-Way Truck Mileage	Miles in Each Population Zone		
		Rural	Suburban	Urban
Argonne National Laboratory-East	1,696	1,412	259	25
Hanford Site	1,807	1,645	144	18
Idaho National Engineering and Environmental Laboratory & Argonne National Laboratory-West	1,392	1,263	114	15
Lawrence Livermore National Laboratory	1,452	1,304	100	48
Los Alamos National Laboratory	341	318	21	2
Mound Plant	1,764	1,359	382	23
Nevada Test Site	1,214	1,137	64	13
Oak Ridge National Laboratory	1,439	1,160	265	14
Rocky Flats Environmental Technology Site	704	619	71	14
Savannah River Site	1,535	1,203	315	17

[a] The mileage from sites with small quantities of waste to the treatment sites can be found in Appendix E.

5.1.8.2 Accidents, Injuries, Fatalities, and Pollution-Related Health Effects from Truck Transportation

Although the transportation of TRU waste cannot be made entirely impact free, reasonable planning and control strategies can usually reduce impacts to a level below that of comparable shipments (for example, commercial shipments of hazardous materials such as gasoline). WIPP would use such strategies to reduce impacts. A complete picture of the planning and control strategies are presented in Appendix C, Appendix L, and Appendix M of SEIS-I, and Appendix E of this document. Appendix C of SEIS-I summarizes emergency response training, procedures, and plans for the WIPP shipping campaign. Appendix L of SEIS-I summarizes the design, certification, and operation of the TRUPACT-II shipping container for CH-TRU waste and the NuPac 72B shipping cask for RH-TRU waste (the RH-72B is very similar in design to the NuPac 72B). Appendix M of SEIS-I (and Section 3.1.2.1 of this document) summarizes a trucking contract, including qualification standards and training requirements for drivers, and quality assurance standards applicable to operational activities. The qualifications and quality assurance standards are essentially unchanged since SEIS-I.

As outlined in the *Transuranic Materials Transportation Guide* (DOE 1996b), the trucking contractor is responsible for the routing of shipments in accordance with federal, state, Tribal, and local regulations. DOE, on behalf of the contractor, has coordinated these routes with the affected states. The DOE Carlsbad Area Office (CAO) is responsible for providing a plan (DOE 1995a) for responding to emergencies involving TRU waste transportation. The plan has been completed and is available upon request. The level of response to an accident would be determined by the DOE Albuquerque Office, based on the type of accident as outlined in the CAO emergency response plan. The levels are defined as 0 through III, with 0 representing the lowest severity (a minor accident), I representing potential penetration of TRU waste packaging, II representing definite penetration, and III representing a definite release or the need for repackaging.

Once the appropriate level of response has been established, a team would respond with the necessary equipment. The team would also coordinate with the carrier to expedite recovery of TRU waste and the packaging. Personnel would be on call 24 hours a day when shipments are en route.

For the SEIS-II analyses of accidents, injuries, and fatalities, truck accident statistics compiled for each state by highway type were used to determine route-specific accident, injury, and fatality rates (Saricks and Kvitek 1994). The route mileage through each state, obtained using HIGHWAY, was multiplied by the state traffic accident, injury, or fatality rates. The products were then summed for the route, and the sums were divided by the total route mileage. With the exception of the State of New Mexico, the accident rate data for federally aided interstate highways were used. For New Mexico, because much of the waste would travel on U.S. Highway 285, the rate for federally aided primary roads was used.

Once the route-specific accident, injury, and fatality rates per route were obtained, they were multiplied by the number of shipments along each route to obtain the estimated number of accidents, injuries, and fatalities. These impacts were estimated using round-trip mileage and adjusted to account for the small number of shipments between the 10 sites with small amounts of waste and the 10 major treatment sites.

For the Proposed Action, 56 accidents, 39 injuries, and 5 traffic-related fatalities were estimated over the transportation period of 35 years. Though rail transportation was not analyzed under the Proposed Action, use of rail transportation is reserved for future consideration under the Preferred Alternative; if rail transportation were used, impacts are expected to be lower. The results are shown in Table 5-6.

Table 5-6
Nonradiological Impacts of Transporting TRU Waste by Truck for the Proposed Action [a]

Impact	CH-TRU Waste	RH-TRU Waste	Total Impact
Number of Accidents	43	13	56
Number of Traffic Injuries	30	9	39
Number of Traffic Fatalities	4	1	5
Pollution Health Effects (fatalities)	0.1	0.04	0.1

[a] All numbers include the impacts from potential transportation between sites with small volumes of waste and the 10 major treatment sites.

Similarly, the estimated pollution health effects due to diesel exhaust are shown in Table 5-6. These are potential cancer fatalities attributed to exposure to diesel exhaust. This health effect is based upon the total miles traveled in urban areas and a factor that estimates vehicle exhaust impacts on the public, 9.9×10^{-8} latent cancer fatalities (LCF) per kilometer (1.6×10^{-7} LCF per mile) (Rao et al. 1982). Urban areas have greater concentrations of vehicle exhaust. These areas sometimes have air quality concerns as well. Urban areas were assumed to have the largest mean population density (3,861 persons per square kilometer [10,000 persons per square mile]). The impacts would be smaller for rural areas, as in much of New Mexico.

5.1.8.3 Accident-Free Radiological Impacts from Truck Transportation

Accident-free radiological impacts occur during the routine transportation of radioactive material and result from direct public and worker exposure to radiation at levels allowed by transportation regulations. While the TRUPACT-II and RH-72B packaging provides radiation shielding, workers, vehicle crew members, and the public along the transportation routes would be exposed to radiation at very low dose rates during transportation. The RADTRAN code (Neuhauser and Kanipe 1992) was used to estimate the impacts due to this radiation. The following categories of accident-free occupational and nonoccupational exposures were estimated (the nomenclature provided in RADTRAN is presented in parentheses):

- ***Along Route*** *(Off Link Exposure):* Exposure to individuals adjacent to routes of travel
- ***Sharing Route*** *(On Link Exposure):* Exposure to individuals sharing the right of way
- ***Stops*** *(Stops):* Exposure to individuals while shipments are at rest stops
- ***Occupational*** *(Occupational Exposure):* Exposure to waste transportation crews

The sum of the first three items in the above list equals the total nonoccupational exposure. The important RADTRAN input parameters related to TRU waste shipment characteristics are the transportation index (TI), which is the exposure rate at 1 meter (3.3 feet) from the container (in mrem per hour); the frequency of vehicle stops; the number of people exposed and their distances from the container; and the speed of the vehicle.

The TI for a TRUPACT-II or RH-72B shipment is a function of the radionuclide content of the waste being shipped. Typically, the radionuclide content of the waste is different for each generator site. For WIPP shipments, an average radionuclide inventory was developed for each site (see Appendix A). The TIs were then calculated. Because of the uncertainty of the TRU waste radionuclide inventory, a conservative TI of 4 (4 mrem per hour at 1 meter) was chosen for all CH-TRU waste shipments and a TI of 10 (10 mrem per hour at 1 meter) for all RH-TRU waste shipments. All of the calculated TIs were less than those used to estimate impacts (for details on the process used to calculate the TIs, see Appendix E).

ESTIMATING RADIOLOGICAL IMPACTS

Estimation of potential human health impacts involves a series of calculations that indicate the potential health consequence of a particular action or accident, and the probability that the action or accident would occur. Impacts can be calculated both for individuals and for a population. The probability of occurrence for routine actions is 1.0, meaning the action (e.g., chronic release from a permitted exhaust point) will occur at regular intervals, typically daily, over a year of operations. The probability of occurrence for accidents, therefore, is between zero and 1.0, indicating that the nonroutine event might be expected to occur at some random point in time over the entire operations period.

The health effect of concern from low levels of radiation exposure is a radiation-induced cancer fatality. To quantify the radiological impact, the radiation dose must be calculated. The dose is a function of the exposure pathway (external, inhalation, or ingestion) and the type and quantity of radionuclides involved. After the dose is estimated, the health impact is calculated from current internationally recognized risk factors. For this document, potential radiological impacts are based on a scenario that includes prudently conservative release, exposure, and risk factor estimates. Because of the use of conservative assumptions, the impact estimates bound any that would be expected.

The unit of radiation dose for an individual is the rem. A millirem (mrem) is 1/1,000 of a rem. The unit of dose for a population is person-rem and is determined by summing the individual doses of an exposed population. Dividing the person-rem estimate by the number of people in the population would indicate the average dose to a single individual. The impacts from a small dose to a large number of people can be approximated by the use of population (i.e., collective) dose estimates.

To estimate the human health impact from radiation dose, a dose-to-risk factor that indicates the potential for a latent cancer fatality, or LCF, is used. An LCF is a fatality resulting from a cancer that was originally induced by radiation, but which may occur years after the exposure. The dose-to-risk factor for low (less than 20 rem) annual doses is 0.0005 LCF per person-rem for the general public, which includes the very young and the very old, and 0.0004 for the worker population. For example, a population dose of 2,000 person-rem is estimated to result in one additional cancer fatality (0.0005 x 2,000 = 1) in the general public. The dose-to-risk factor for an individual is doubled if the individual dose is greater than 20 rem/year (20,000 mrem per year).

The average individual in the United States receives a dose of 0.3 rem (300 mrem) each year from background radiation. Background radiation sources include radon that has concentrated in homes from foundation soil sources, uranium found in rocks used as building materials, and cosmic radiation from the earth's atmosphere. The average lifetime chance or probability of cancer to a member of the public from a 70-year exposure due to background radiation is 0.01 (70 x 0.3 x 0.0005). That is, the best current radiation risk estimates are that one in 100 people will die from cancer due to background radiation.

The accident-free radiological impacts are presented in Table 5-7. These impacts were estimated using factors of 4×10^{-4} LCF per person-rem for occupational exposures and 5×10^{-4} LCF per person-rem for nonoccupational exposures (ICRP 1991). Table 5-7 also summarizes the impacts to those living along routes, those in vehicles sharing the routes, and those exposed during stops for both CH-TRU and RH-TRU waste shipments. The accident-free impacts for transporting TRU waste under the Proposed Action include the impacts associated with the potential consolidation of TRU waste from those sites with smaller quantities of waste. These impacts contribute approximately 1 percent to the total accident-free transportation impacts under the Proposed Action.

Table 5-7
Aggregate Accident-Free Population Radiological Impacts from Truck Transportation for the Proposed Action (LCFs) [a]

Exposure Category	CH-TRU Waste	RH-TRU Waste	Total
Occupational	0.3	0.03	0.3
Nonoccupational			
Stops	2	0.8	2.8
Sharing Route	0.1	0.05	0.2
Along Route	0.04	0.02	0.06
Nonoccupational Total	2.1	0.9	3.0

[a] Exposure during stops is based upon 50 individuals exposed at 20 meters. Stop time, in hours, is based upon 0.011d where d is the distance traveled in kilometers. These parameters are built into the RADTRAN code but substantially overestimate exposures from WIPP shipments.

A total of 3.0 nonoccupational LCFs are estimated due to routine transportation under the Proposed Action. However, default parameters of the RADTRAN code substantially overestimate impacts due to WIPP shipments. Because WIPP shipments would use two-driver teams (eliminating the need for overnight stops to sleep) and because the shipments would stop at sites chosen, in part, because they are not near population centers, the actual impacts from stops would be much lower.

Accident-free radiological impacts include the probability of incurring an LCF for maximally exposed individuals (MEI). The assumptions and scenarios used to determine the MEIs were as follows:

- *Individual stuck in traffic next to a truck transporting TRU waste*. For this assessment, it was assumed that the individual would have an exposure distance of 1 meter (3.3 feet) for an exposure time of 30 minutes. The individual was assumed to be exposed only once.

- *An inspector of trucks ready for departure*. For this assessment, it was assumed that the inspector would have an exposure distance of 1 meter (3.3 feet) for 30 minutes, that the inspector would work at the same job for 10 years, and that there would be three shifts working the same job. The number of shipments inspected would depend on the total number of shipments to be shipped from the site and the rate at which they would be shipped. In actuality, in accordance with current DOE administrative requirements, such an inspector's dose would be limited through radiation monitoring, and the inspector would be rotated into a new job should his or her dose climb to the administrative limit. In order to be conservative, this administrative requirement was not taken into consideration for SEIS-II analyses.

- *A person who performs state vehicle safety inspections*. For this assessment, it was assumed that the individual would inspect 20 percent of the TRU waste shipments, that the inspector would work at the same job for 10 years, and that the average exposure distance would be approximately 1 meter (3.3 feet) for 1 hour. To bound the state inspector's dose, it was assumed that the individual would work on the route on which the majority of the waste enters New Mexico. Again, in actuality this person's dose would be limited by administrative rules and the inspector would be rotated into a new position. In order to be conservative, this was not taken into consideration for SEIS-II analyses.

UNDERSTANDING SCIENTIFIC AND EXPONENTIAL NOTATION

Scientific notation is used in this document to express numbers that are so large or so small that they can be difficult to read or write. Scientific notation is based on the use of positive and negative powers (or exponents) of 10. A number written in scientific notation is expressed as the product of a number between 1 and 10 and a positive or negative power of 10. Examples include the following:

Positive Powers of 10	**Negative Powers of 10**
$10^{1} = 10 \times 1 = 10$	$10^{-1} = 1/10 = 0.1$
$10^{2} = 10 \times 10 = 100$	$10^{-2} = 1/100 = 0.01$
and so on, therefore,	and so on, therefore,
$10^{6} = 1{,}000{,}000$ (or 1 million)	$10^{-6} = 0.000001$ (or 1 in 1 million)

A power of 10 is also commonly expressed as "E", where "E" means "x 10". For example, 3×10^{5} can also be written as 3E+5, and 3×10^{-5} is equivalent to 3E-5. Therefore, 3E+5 = 300,000 and 3E-5 = 0.00003. This is called exponential notation.

The data tables in this section use exponential notation for numbers that are either very large or very small. The text uses scientific notation to convey these numbers.

Probability is expressed as a number between 0 and 1 (0 to 100 percent likelihood of the occurrence of an event). The notation 3E-6 can be read 0.000003, which means that there are three chances in 1,000,000 that the associated result (e.g., fatal cancer) will occur in the period covered by the analysis.

- *Individual residing along a shipment route*. For this assessment, it was assumed that the individual would have an exposure distance of 30 meters (100 feet) over a 70-year period.

- *Individual who is a rest stop employee*. For this assessment, it was assumed that all trucks stop at the same location, that there are three shifts working at the truck stop, and that the individual works at the truck stop for 10 years. It was estimated that the individual would be exposed to 20 percent of all TRU waste shipments sent to WIPP over a 10-year period. The individual was assumed to be exposed over a 2-hour stop duration at a distance of 20 meters (66 feet).

Table 5-8 summarizes the maximum probability of incurring an LCF for these individuals. The departure and state inspectors would have the highest probability of health effects due to the performance of their responsibilities associated with TRU waste shipments.

Table 5-8
Lifetime Accident-Free Radiological Impacts to MEIs from Truck Transportation for the Proposed Action (Probability of an LCF)

MEI	CH-TRU Waste	RH-TRU Waste	Total
Stuck in traffic next to TRU waste shipment	2.5E-6	5.0E-6	7.5E-6
Departure Inspector	2.4E-3	1.6E-3	4.0E-3
State Vehicle Inspector	4.6E-3	3.9E-3	8.5E-3
Residing adjacent to access route	2.5E-4	1.5E-4	4.0E-4
Rest stop employee	1.5E-4	3.5E-4	5.0E-4

5.1.8.4 Radiological Impacts from Truck Transportation Accidents

As part of the U.S. Nuclear Regulatory Commission (NRC) package certification process, computer simulations are used to model the behavior of packaging in a series of tests that are internationally recognized to represent a severe accident. These simulations are followed by physical tests. By comparing the results of the physical tests with the simulation results, it is possible to conclude, with a high degree of confidence, that a properly constructed and maintained package will not be breached in all but a small number of accidents in which forces imposed on the packaging are much more severe than the tests. This section looks at the impacts associated with the small fraction of severe accidents that would cause the release of radioactive material.

Two types of analyses were conducted for SEIS-II radiological impacts from accidents. For the first type of analysis, the RADTRAN code was used to estimate the radiological impact from accidents during transport from each of the assumed 10 major treatment sites to WIPP. For this analysis, a conservative radionuclide inventory was used; it was assumed every TRU waste package would be filled with waste containing the highest level of radionuclides and hazardous material allowable by the planning-basis WAC. The first type of analysis took into account eight different severity categories of accidents, their probabilities of occurrence, the distance from each site, and the number of shipments. The total accident risk from each of the 10 sites was obtained by summing the risks calculated for the severity categories. A complete discussion of these analyses is included in Appendix E.

Assumptions for these analyses included the following:

- Release fractions increase with the severity category.
- Because the TRUPACT-II and RH-72B must endure severity category I and II accidents without a breach, no release was calculated for these two severity categories.
- Only one of the TRUPACT-IIs in a shipment would be breached in an accident of any of the severity categories. This assumption is based on studies that indicate hard targets along roadways are too few or are of the wrong orientation to cause the breach of more than one TRUPACT-II (see Appendix E).

FRACTIONAL LCFs

Sometimes, calculations of the number of latent cancer fatalities associated with radiation exposure do not yield whole numbers, and, especially in environmental applications, may yield numbers less than 1.0. For example, if each member of a population of 100,000 were exposed to a total dose of 0.001 rem, the collective dose would be 100 person-rem, and the corresponding estimated number of latent cancer fatalities would be 0.05 (100,000 persons x 0.001 rem x 0.0005 latent cancer fatalities/person-rem = 0.05 latent fatal cancers).

How should one interpret a nonintegral number of latent cancer fatalities, such as 0.05? The answer is to interpret the result as a statistical estimate. That is, 0.05 is the *average* number of deaths that would result if the same exposure situation were applied to many different groups of 100,000 people. For most groups, no one would incur a latent cancer fatality from the 0.001 rem dose each member would have received. In a small fraction of the groups, 1 latent fatal cancer would result; in exceptionally few groups, 2 or more latent fatal cancers would occur. The *average* number of deaths over all of the groups would be 0.05 latent fatal cancers (just as the average of 0, 0, 0, and 1 is ¼ or 0.25). The most likely outcome is 0 latent cancer fatalities.

ESTIMATING ACCIDENT RISK

Assessing the radiological or hazardous chemical impact due to accidents is typically done by estimating the probability that such an accident might occur and, for a selection of accidents, by estimating the accident's consequences. The probability, or chance, that the accident will occur, and the consequences of the accident are multiplied together to determine the total risk of the accident.

Accident probability is usually determined by historical information on accidents of a similar type or severity. Determining accident consequences requires estimation of the quantity of radionuclides or hazardous chemicals likely to be released, the exposure pathways that will bring the radionuclides or hazardous chemicals into contact with people, and the environmental transport mechanisms. Because of the many variables in these calculations, conservative or bounding assumptions are commonly used and risks tend to be overestimated.

- Only one RH-72B is transported per truck. That one cask would be breached.
- The population densities used to estimate impacts were six persons per square kilometer (16 per square mile) for rural areas, 719 persons per square kilometer (1,863 per square mile) for suburban areas, and 3,861 persons per square kilometer (10,000 per square mile) for urban areas.
- The analyses assumed that stable atmospheric conditions predominated, maximizing impacts.
- Impacts were calculated using a resuspension particle half-life of 365 days.

The results for the first type of accident analysis, route-specific accidents summed over the entire shipping campaign, are presented in Table 5-9.

Table 5-9
Aggregate Radiological Impacts from Potential Truck Transportation Accidents for the Proposed Action (LCFs) [a]

Waste Origin	CH-TRU Waste	RH-TRU Waste	Total
Argonne National Laboratory-East	5.0E-4	---	5.0E-4
Hanford Site	0.3	4.0E-3	0.3
Idaho National Engineering and Environmental Laboratory & Argonne National Laboratory-West	0.08	2.6E-3	0.08
Lawrence Livermore National Laboratory	1.5E-3	---	1.5E-3
Los Alamos National Laboratory	3.5E-3	1.5E-5	3.5E-3
Mound Plant	1.0E-3	---	1.0E-3
Nevada Test Site	5.0E-4	---	5.0E-4
Oak Ridge National Laboratory	3.0E-3	1.0E-3	4.0E-3
Rocky Flats Environmental Technology Site	8.0E-3	---	8.0E-3
Savannah River Site	0.02	---	0.02
Total	**0.42**	**7.6E-3**	**0.43**

[a] Includes both probability of the accident and consequences.

A 1987 NRC study estimated that only 0.6 percent of truck and rail accidents involving Type B containers or casks could cause a radiation hazard to the public (Fischer et al. 1987). There are 56 potential accidents under the Proposed Action, and only half of these accidents are expected to occur when the canister or cask is loaded. Therefore, of the approximately 28 potential transportation accidents estimated to occur under the Proposed Action when the canister or cask is loaded, none would be expected to result in package failure. Still, the second type of analysis was an assessment of four bounding accidents: two assumed a breach of a TRUPACT-II and two assumed a breach of an RH-72B cask. The accidents were assumed to occur under conditions that would maximize, within reasonable bounds, the impacts to exposed population groups. Assumptions for these analyses included the following (see Appendix E for details):

- During the accidents, one TRUPACT-II or RH-72B cask would be breached.
- Each accident would occur in an urban area with a population density of 3,861 persons per kilometer (10,000 persons per square mile), under stable atmospheric conditions that would maximize exposure to nearby populations.
- Two types of inventories were considered for the four accidents: a conservative inventory similar to that used for the first type of analysis above and an inventory based on the average concentrations of radionuclides and hazardous chemicals at Hanford (for RH-TRU waste) and SRS (for CH-TRU waste). The conservative inventory was determined by maximizing the concentrations of radionuclides and hazardous chemicals to the limits allowed by the planning-basis WAC.
- Breach of the TRU waste packaging would result in 0.02 percent of the radioactive material being released to the environment in a respirable form (DOE 1990).
- Impacts were calculated using a resuspension particle half-life of 365 days.

The results for the second type of accident analysis follow. The probability of an accident that would breach a Type B package is 7.5×10^{-7} per accident.

- For the accident with the conservative inventory in a breached TRUPACT-II, the estimated dose would result in 16 LCFs in the exposed population. The estimated maximum individual dose would result in a 0.06 probability of an LCF. The estimated population doses were dominated by inhalation contributions (initial or from resuspension).
- For the accident with a conservative inventory in a breached RH-72B, the estimated dose would result in 16 LCFs in the exposed population. The estimated maximum individual dose would result in a 0.06 probability of an LCF.
- For the accident with average concentrations of radionuclides and hazardous chemicals in a breached TRUPACT-II, the dose estimated would result in 3 LCFs in the exposed population. The estimated maximum individual dose would result in a 0.04 probability of an LCF.
- For the accident with average concentrations of radionuclides and hazardous chemicals in a breached RH-72B, the total population dose estimated would result in a 0.04 LCF in the exposed population. The estimated maximum individual dose would result in a 7×10^{-4} probability of an LCF.

TRANSPORTATION IMPACTS OF THE SANTA FE BYPASS

The Santa Fe Bypass route is an established New Mexico Highway and Transportation Department project that provides for alternative routing for radioactive materials around the Santa Fe, New Mexico urban area. It is a route 22.24 kilometers (13.82 miles) long and connects US-285 north of Santa Fe with I-25 southwest of Santa Fe. The location study was completed in 1985 and adopted by the city on January 8, 1986. To date, approximately two-thirds of the route has been completed; the final one-third has been designed and was originally scheduled for late 1997. However, negotiations are being conducted at this time for the right-of-way for the final phase.

To compare the impacts of using St. Francis Drive to access I-25 through Santa Fe or the Santa Fe bypass under the Proposed Action, the impacts of shipping TRU waste from LANL to WIPP was reevaluated using the Santa Fe bypass route. By this method, the total number of miles traveled would increase from approximately 550 kilometers (342 miles) to 575 kilometers (357 miles). Using the bypass eliminates about 3.2 kilometers (2 miles) of travel in an urban population zone and 7.2 kilometers (4.5 miles) in a suburban population zone along St. Francis Drive. Using the bypass adds approximately 29 kilometers (18 miles) of travel in a suburban population zone and 6.4 kilometers (4 miles) in a rural population zone. The additional 29 kilometers (18 miles) includes 13 kilometers (8 miles) along federally aided interstate (I-25) and 16 kilometers (10 miles) along federally aided primary road (the bypass). The rural miles are along the bypass and are classified as federally aided primary road. The road classifications (federally aided interstate and federally aided primary road) are identified because the accident rates are based upon state-specific data for those road types (Saricks and Kvitek 1994). The following table compares the impacts of shipping TRU waste from Los Alamos to WIPP using the Santa Fe bypass or St. Francis Drive.

Impact	Santa Fe Bypass	St. Francis Drive
Nonradiological		
Accidents	3.3	2.8
Injuries	3.1	2.7
Fatalities	0.5	0.4
Radiological Accident-Free		
Dose, in rem (LCFs in parentheses)		
Occupational	32.1 (0.013)	30.7 (0.012)
Non-occupational	201.2 (0.101)	192.6 (0.096)

5.1.8.5 Hazardous Chemical Impacts from Severe Truck Transportation Accidents

This section estimates the impacts associated with exposure to hazardous constituents (as defined by the Resource Conservation and Recovery Act [RCRA]) during the transportation of TRU mixed waste to WIPP. Hazardous chemicals in TRU waste include VOCs and certain metals listed as hazardous chemicals in RCRA. During routine transportation of TRU mixed waste, exposures to hazardous chemicals would not occur because the TRUPACT-II and RH-72B packagings are not vented, and the hazardous chemical components in the waste are completely contained. No impacts to human health would be posed by the hazardous constituents under routine transportation conditions. Impacts due to accidents, however, are possible. It is those impacts that are evaluated in this section.

Hazardous chemical inventories were developed as described in Appendix A. For those VOCs where maximum allowable levels are stipulated in the planning-basis WAC, those levels were assumed to be in the container being transported during an accident. Where no maximum level was specified in the planning-basis WAC, the highest level found during waste drum sampling was

selected to ensure that the typical concentration is bounded. For heavy metals, the concentration was assumed to be the average of those found during sampling (see Section A.5).

It was assumed that CH-TRU waste hazardous chemical accident scenarios would bound any impacts from RH-TRU waste shipments; therefore, no hazardous chemical accidents were analyzed for RH-TRU shipments. The bases for this assumption included the relative shipment capacity (hazardous chemical inventory) of 14 CH-TRU waste drums or 2.91 cubic meters (103 cubic feet)

ESTIMATING HAZARDOUS CHEMICAL IMPACTS

Hazardous chemical exposures can pose two types of health effects, carcinogenic (causing cancer) and noncarcinogenic (for example, respiratory problems or skin irritation). Some hazardous chemicals can potentially produce both carcinogenic and noncarcinogenic health effects. Health effect analyses require knowledge of the exposure pathway and intake (typically by inhalation, but also by ingestion), and use of health effect risk factors that allow estimated intakes to be converted to estimates of health effects.

Carcinogenic Risk

Carcinogenic risk is probabilistic; that is, every intake carries with it some probability of cancer incidence regardless of how small the intake is. The risk varies linearly with exposure, and there is assumed to be no threshold below which an effect would not occur. The U.S. Environmental Protection Agency (EPA) has published carcinogenic risk factors to be used for estimating potential impacts from chronic (long-term) exposure to hazardous chemicals. The "slope factor" of a hazardous chemical is used to convert chronic hazardous chemical intakes to the probability of cancer incidence. The chronic exposure is assumed to last for a 70-year lifetime. Slope factors are specified as the risk per average daily intake over that 70-year period.

No standard method exists to calculate the carcinogenic risk from an acute (one-time or short-term) intake. The method selected for SEIS-II analyses used the chronic-exposure slope factors and assumed the total acute intake was averaged over the 70-year lifetime. In practice then, slope factors were used but specified as the risk per total acute intake.

Noncarcinogenic Health Effects

In contrast to carcinogenic health effects, noncarcinogenic health effects are deterministic, not probabilistic; that is, these effects are assumed to have an exposure threshold, and unless that threshold is reached no health effect would occur. EPA "reference doses" were used to estimate the potential noncarcinogenic health effects from chronic exposure to hazardous chemicals. Reference doses are specified as the chronic daily intake that would be required for the health effect to occur.

As was the case for acute exposures to carcinogenic hazardous chemicals, no standard method exists for estimating the noncarcinogenic health effects from acute exposures to hazardous chemicals. The method selected for SEIS-II analyses used the National Institute of Occupational Safety and Health (NIOSH) immediately dangerous to life or health (IDLH) values, or calculated IDLH-equivalent intakes. IDLH values are the air concentrations that would result in serious or life-threatening health effects if an individual were to be exposed at that concentration for 30 minutes. IDLH-equivalent intakes were calculated using the IDLH parameters to estimate potential impacts from exposure times less than 30 minutes. The IDLHs are air concentrations with units of milligrams per cubic meter (mg/cubic meter) or parts per million (ppm) of the hazardous chemical in air. IDLH-equivalent values are in mass quantities of intake, such as milligrams (mg).

of waste compared to the capacity of an RH-72B cask or 0.89 cubic meters (32 cubic feet) of waste. A TRUPACT-II, therefore, is likely to hold nearly three times the hazardous chemicals that an RH-72B would hold. For the purpose of analysis, it was assumed that the RH-TRU waste hazardous chemical inventory is the same as the CH-TRU hazardous chemical inventory.

The approach used to assess human health effects from hazardous chemical exposures during transportation accidents was similar to that used for SEIS-I. The assessment criteria used were the immediately dangerous to life or health (IDLH) values provided by the National Institute of Occupational Safety and Health (NIOSH). Each chemical was considered separately; the impacts from each chemical are not additive. As long as the ratio of possible intake to IDLH value was less than 1, the risk of health impact was considered zero, and there was no need to further evaluate an exposure. The hazardous constituents that were analyzed are presented in Table 5-10.

Hazardous chemical impacts were evaluated for a bounding, severity category VIII accident. The accident would breach one of the three TRUPACT-IIs. The entire TRUPACT-II inventory of VOCs was assumed to be released (release fraction = 1.0), and heavy metals would be released as particulates with a release fraction of 2×10^{-4} (DOE 1990). The receptor was assumed to be a public MEI located 1,000 meters (3,300 feet) downwind from the accident, exposed at the centerline of the released plume of chemicals for two hours under stable meteorological conditions and low wind speed. Table 5-10 presents the hazardous chemicals analyzed and impacts to the MEI as a fraction of the chemical-specific IDLH value. For all chemicals analyzed, the concentration to which the MEI would be exposed would be no more than about 1/10,000th of the chemical's IDLH value. Therefore, no human health effects would be expected from acute exposure to hazardous chemicals released from a severe transportation accident.

Table 5-10
Hazardous Chemical Impacts for a Severe Truck Transportation Accident for the Proposed Action [a]

Chemical	IDLH (parts per million)	IDLH (milligrams per cubic meter)	Receptor Concentration (milligrams per cubic meter)	Fraction of IDLH Value
Carbon Tetrachloride	200	1,278	5.4E-04	4.2E-07
Chloroform	500	2,480	3.1E-05	1.3E-08
Methylene Chloride	2,300	8,119	1.1E-03	1.3E-07
1,1,2,2-Tetrachloroethane	100	700	1.4E-03	2.0E-06
Chlorobenzene	1,000	4,680	2.0E-04	4.4E-08
Methyl Ethyl Ketone	3,000	9,000	4.0E-04	4.5E-08
Toluene	500	1,915	1.3E-04	7.0E-08
1,2-Dichloroethane	50	206	1.1E-04	5.1E-07
Beryllium	---	4	5.5E-03	1.4E-03
Cadmium	---	9	8.8E-05	9.8E-06
Lead	---	100	2.2E-01	2.2E-03
Mercury	---	10	9.4E-02	9.4E-03

[a] Assumes a severity category VIII accident of a CH-TRU waste shipment.

5.1.9 Human Health Impacts from Waste Treatment and Disposal Operations

This section presents human health impacts to the public, noninvolved workers, and involved workers from waste treatment and waste disposal operations under the Proposed Action. Throughout this section, the potential impacts from treating waste to planning-basis WAC and from the disposal operations at WIPP are reported separately.

Impacts from waste treatment under the Proposed Action were adjusted from those presented in the WM PEIS (DOE 1997); a description of this adjustment is provided in Appendix B. Treatment of the waste may result in the release of radioactive materials or hazardous chemicals, impacting the public and workers who would not directly handle waste (noninvolved workers).

Direct radiation from the waste would present potential radiological impacts for workers who would handle waste (involved workers) at the treatment sites. The public MEI impact is presented for the site with the highest estimated impact of all sites evaluated in the WM PEIS. Population impact estimates from waste treatment are the sum of all population impact estimates for all treatment sites.

UNCERTAINTIES IN TRANSPORTATION IMPACT ANALYSES

To account for inherent uncertainties in the data, conservative assumptions were made so that reported impacts would bound potential impacts. The following are descriptions of the sources of uncertainty.

Waste Inventory and Characterization

The physical form and radionuclide content of TRU waste were considered when estimating both the external dose rate during accident-free transport and the dose to exposed individuals from transportation accidents. Therefore, conservative assumptions were applied consistently to the waste data to limit potential differences between sites and across alternatives.

Route Determination

Although highway infrastructure and demographics may change considerably over the next 35 to 190 years, representative routes were established for all origin and destination sites in each of the alternatives. The routes were determined using current guidelines, regulations, and practices.

Radiation Doses

Based on the natural variability of key physical processes (i.e., atmospheric dispersion of radioactive material), conservative assumptions were made regarding radiation dose assessment for transportation activities. Parameter values were selected that would provide reasonable upper limits or, in some cases, bounding estimates of potential impacts. Because parameters and assumptions were applied consistently to all alternatives, the relative comparisons between alternatives would not be affected.

For TRU waste shipments, the largest dose contributors were found to be: (1) accident-free dose to members of the public at stops; (2) accident-free dose to transportation crew members; (3) accident-free dose to members of the public sharing the route; (4) accident-free dose to members of the public living along the route; (5) accident dose risk to members of the public in an urban population zone (mean density of 3,861 persons per kilometer). Approximately 80 percent of the estimated public dose would be incurred at stops, 15 percent would be incurred by the members of the public sharing the route, and 5 percent would be incurred by members of the public living along the route.

Potential impacts from WIPP waste handling and emplacement operations were calculated for the public living near WIPP, for WIPP noninvolved workers, and for WIPP involved workers. Potential impacts from routine releases of VOCs and radioactive gases were calculated because each waste drum or waste box would be vented to reduce gas buildup. Both workers and the public may be exposed to these releases. No release of particulate hazardous chemicals during routine operations would occur at WIPP because the vents on the drums have filters, and the drums would not be opened. For the involved workers, potential impacts also were calculated for exposure to direct radiation from waste container contents. Direct radiation impacts for others at WIPP were not calculated because of the distances between where the drums would be unloaded and emplaced and other work areas. The impacts from the disposal operations were calculated for releases occurring after waste is unloaded from the TRUPACT-II or RH-72B. The detailed methods and assumptions used to calculate the potential impacts are described in Appendix F.

The types and concentrations of VOCs in the TRU mixed waste were estimated from past sampling of CH-TRU waste containers (see Appendix A). Emissions from CH-TRU and RH-TRU waste containers were assumed to have similar concentrations of VOCs. Although an estimated 60 percent of the TRU waste is mixed waste, all TRU waste was considered TRU mixed waste for human health analyses. Weighted average headspace concentrations (concentrations in the void area of a drum) were estimated for waste at each treatment site and were used to estimate impacts from waste emplaced underground at WIPP. More conservative estimates of VOC emissions were used to estimate impacts to workers in the Waste Handling Building. The limited number of drums (or drum-equivalents if the waste is in other containers) that could be present in the Waste Handling Building were assumed to release quantities of VOCs based on weighted maximum headspace concentrations; this assumption was made to bound the potential impacts to a worker in this facility.

Radiological impacts are presented as the estimated number of LCFs in a population, and, for individuals, as the probability of an LCF. As with the transportation analyses, the International Commission on Radiological Protection (ICRP) Publication 60 (ICRP 1991) dose-to-risk factors of 5×10^{-4} LCF per person-rem for the general public and 4×10^{-4} LCF per person-rem for the worker population were used to convert radiation dose to LCFs.

Impacts resulting from chronic exposure to hazardous chemicals may be either carcinogenic or noncarcinogenic. Carcinogenic impacts are presented as the estimated cancer incidence (number of cancers occurring) in a population and, for MEIs, as the probability of cancer occurring. The Environmental Protection Agency's (EPA) slope factors were used to estimate cancer incidence from chronic exposure to hazardous chemicals. Noncarcinogenic health effects were evaluated using a hazard index (HI), which is the ratio of the

RADIOLOGICAL IMPACTS OTHER THAN LCFs

For SEIS-II, the impact reported from a radiation dose is the number of LCFs that may occur in a population, and the probability of an LCF occurring in a maximally exposed individual. Other radiological impacts could result from exposure, such as a nonfatal cancer or hereditary effects (physical deformities). The risk of an LCF, however, is the dominant risk.

For the general public, consideration of nonfatal cancers would increase the impact estimate by 20 percent and, for severe hereditary effects, the impact estimate would increase by another 20 percent. For workers, consideration of nonfatal cancers would increase the impact estimate by 20 percent and for severe hereditary effects, by an additional 26 percent (ICRP 1991).

estimated annual intake of a specific chemical divided by the EPA reference dose for that chemical (see the "Estimating Hazardous Chemical Impacts" text box). An HI greater than 1 would predict the occurrence of the chemical-specific noncarcinogenic health effect. Estimates of the HI for involved workers for some prospective cases (such as WIPP waste handling) were done very conservatively, and resulted in an HI greater than 1. In these cases additional evaluations were made.

The air concentration to which the worker would be exposed was conservatively calculated and compared to the Occupational Safety and Health Administration's (OSHA) permissible exposure limit (PEL) values. The PELs are, typically, time-weighted averages that must not be exceeded during any 8-hour work shift or a 40-hour work week. A few hazardous chemicals that may be present in waste accepted at WIPP have PEL values that must not be exceeded over any time period; they are chloroform, methylene chloride, and beryllium. If the air concentration of the hazardous chemical of concern did not exceed the PEL, no worker noncarcinogenic health effects would occur for the scenario evaluated. Evaluation of the potential for noncarcinogenic health effects in waste treatment workers may be expressed as an exposure index, rather than an HI. This methodology was used in the WM PEIS and is based on the ratio of the exposure level divided by an occupational exposure limit, rather than by the reference dose.

5.1.9.1 Public

Impacts to public populations and to the MEIs under the Proposed Action are presented in this section; results are presented in Table 5-11. Impacts from waste treatment and from WIPP disposal operations are presented separately because different populations and individuals would be impacted by these activities. Waste treatment would take place at multiple DOE sites that would not include WIPP, while disposal operations would take place only at WIPP. Population impacts were estimated for those members of the public residing within 80 kilometers (50 miles) of each treatment facility and WIPP. The MEI from waste treatment is presented for the highest individual waste treatment site, while the MEI from disposal operations would be near the WIPP site. See Chapter 3 for information on where potential treatment could occur.

Table 5-11
Lifetime Human Health Impacts to the Public
from Waste Treatment and WIPP Disposal Operations for the Proposed Action

Category	Waste Treatment Impacts [a]		WIPP Disposal Operations Impacts	
	Radiological (LCF) [b]	Hazardous Chemicals (Cancer Incidence)	Radiological (LCF) [b]	Hazardous Chemical (Cancer Incidence)
MEI [c, d]				
CH-TRU Waste	2E-9 (R)	2E-12 (X)	3E-7	3E-8
RH-TRU Waste	6E-11 (L)	2E-11 (O)	3E-10	1E-9
Total Waste	2E-9 (R)	2E-11 (O)	3E-7	3E-8
Population [c]				
CH-TRU Waste	2E-4	1E-7	3E-4	2E-5
RH-TRU Waste	1E-6	4E-7	4E-7	9E-7
Total Waste	2E-4	4E-7	3E-4	2E-5

[a] Adapted from the WM PEIS (DOE 1997).
[b] The probability of an LCF occurring in the MEI, and number of LCFs occurring in the exposed population.
[c] The MEI and populations evaluated for treatment impacts and WIPP disposal operations impacts are different.
[d] L = LANL, O = ORNL, R = RFETS, X = LLNL

Waste Treatment

No radiation-related LCFs (2×10^{-4} LCFs) or cancer incidence (4×10^{-7} cancers) would be expected in the total population around the waste treatment sites. The MEIs with the greatest impact would be at RFETS for radiological impacts (2×10^{-9} probability of an LCF) and at ORNL for hazardous chemical impacts (2×10^{-11} probability of a cancer incidence). No noncarcinogenic health effects are predicted. The maximum HI for the MEI would be 3×10^{-10}, and no health effect is predicted unless the HI is 1 or higher.

WIPP Disposal Operations

No LCFs would be expected in the population around WIPP from radiation exposure (3×10^{-4} LCFs). VOC releases were estimated by assuming that a single panel, fully emplaced with RH-TRU and CH-TRU waste (4.5 percent and 95.5 percent of panel waste volume, respectively) would release VOCs continuously throughout all 35 years of WIPP disposal operations. Because each panel would be filled over a 2.5-year period and then closed, reducing VOC releases, the assumption of a full panel continuously releasing VOCs is conservative. Still, no cancer incidence (2×10^{-5} cancers) would be expected in the population from hazardous chemical exposure.

The MEI was assumed to be located at the Land Withdrawal Area boundary, the closest point at which an individual could reside. The MEI would have a 3×10^{-7} probability of an LCF from radiation exposure, and a 3×10^{-8} probability of a cancer incidence from hazardous chemical exposure. No noncarcinogenic health effects would occur. The maximum HI for the MEI would be 7×10^{-5}, and no health effect is predicted unless the HI is 1 or higher.

5.1.9.2 Noninvolved Workers

Impacts to the noninvolved worker population and the maximally exposed noninvolved worker under the Proposed Action are presented in this section; results are presented in Table 5-12. A noninvolved worker is an employee who works at a site but is not directly involved in the treatment, storage, handling or disposal of waste. Impacts from waste treatment and from WIPP disposal operations are presented separately because different noninvolved worker populations and individuals would be impacted by these activities. Waste treatment would take place at multiple DOE sites that would not include WIPP, while disposal operations would take place only at WIPP. Noninvolved worker population impacts were estimated for the total of all treatment sites, and for WIPP. The impact to the maximally exposed noninvolved worker from waste treatment is presented for the highest individual waste treatment site, while the maximally exposed noninvolved worker from disposal operations was assumed to work continuously at the WIPP location where emissions have the least atmospheric dispersion and thus the greatest potential impact. This location was assumed to be 200 meters (660 feet) east of the exhaust filter building. The maximum ground-level concentrations of any airborne contamination would be expected at this location.

Waste Treatment

No LCFs (7×10^{-6} LCFs) would be expected in the total noninvolved worker population at the waste treatment sites, and no cancer incidence (1×10^{-7} cancers) would be expected in the total noninvolved worker population from hazardous chemical exposure. The maximally exposed noninvolved worker would be at RFETS for radiological impacts (3×10^{-9} probability of an LCF)

Table 5-12
Lifetime Human Health Impacts to Noninvolved Workers
from Waste Treatment and WIPP Disposal Operations for the Proposed Action

Category	Waste Treatment Impacts [a]		WIPP Disposal Operations Impacts	
	Radiological (LCF) [b]	Hazardous Chemicals (Cancer Incidence)	Radiological (LCF) [b]	Hazardous Chemical (Cancer Incidence)
Maximally Exposed Noninvolved Worker [c, d]				
CH-TRU Waste	3E-9 (R)	6E-12 (X)	4E-7	1E-7
RH-TRU Waste	3E-11 (L)	1E-10 (O)	7E-10	5E-9
Total Waste	3E-9 (R)	1E-10 (O)	4E-7	1E-7
Population Noninvolved Worker [c]				
CH-TRU Waste	7E-6	2E-8	4E-4	1E-4
RH-TRU Waste	7E-8	1E-7	7E-10	5E-6
Total Waste	7E-6	1E-7	4E-4	1E-4

[a] Adapted from the WM PEIS (DOE 1997).
[b] The probability of an LCF occurring in the maximally exposed noninvolved worker, and the number of LCFs in the population.
[c] The individuals and populations evaluated for treatment impacts and operations impacts are different.
[d] R = RFETS, O = ORNL, L = LANL, X = LLNL

and at ORNL for hazardous chemical impacts (1×10^{-10} probability of a cancer incidence). No noncarcinogenic health effects are predicted. The maximum HI for the maximally exposed noninvolved worker would be 3×10^{-9}, and no health effect is predicted unless the HI is 1 or higher.

WIPP Disposal Operations

No LCFs would be expected in the WIPP noninvolved worker population from radiation exposure (4×10^{-4} LCFs). VOC release estimates were the same as for the public. No cancer incidence (1×10^{-4} cancers) would be expected in the noninvolved worker population from hazardous chemical exposure. All 1,095 WIPP employees were assumed to be exposed at the same level as the maximally exposed noninvolved worker.

The maximally exposed noninvolved worker would have a 4×10^{-7} probability of an LCF from radiation exposure and a 1×10^{-7} probability of a cancer incidence from hazardous chemical exposure. No noncarcinogenic health effects would occur. The maximum HI for the maximally exposed noninvolved worker was found to be 6×10^{-4}, and no health effect is predicted unless the HI is 1 or higher.

Appendix F provides additional information on the methods used to determine impacts to noninvolved workers from WIPP disposal.

5.1.9.3 Involved Workers

Impacts to the involved worker populations under the Proposed Action are presented in this section; results are presented in Table 5-13. Involved workers are those directly involved in day-to-day waste treatment, disposal, and management activities. At the waste treatment facilities, such workers would include those who are in direct contact with waste during treatment or packaging to meet planning-basis WAC. At WIPP, they would include workers in the Waste

Table 5-13
Lifetime Human Health Impacts to Involved Workers
from Waste Treatment and WIPP Disposal Operations for the Proposed Action

Category	Waste Treatment Impacts [a]		WIPP Disposal Operations Impacts	
	Radiological (LCF)	Hazardous Chemicals (Cancer Incidence)	Radiological (LCF)	Hazardous Chemical (Cancer Incidence)
Involved Worker Population [b]			(36 workers)	(36 workers)
CH-TRU Waste	0.7	8E-6	0.4 to 0.5	9E-3
RH-TRU Waste	0.02	7E-6	≤0.5	5E-4
Total Waste	0.8	2E-5	≤1	< 0.01

[a] Adapted from the WM PEIS (DOE 1997).
[b] The involved worker populations evaluated for treatment impacts and WIPP disposal operations impacts are different.

Handling Building and those who would emplace waste underground. All worker exposures to radiation and hazardous chemicals would be controlled to as low as reasonably achievable (ALARA) levels. Administrative controls such as worker and area monitoring, rotation of workers to reduce exposures, and standard operating procedures would be used to limit exposures.

Waste Treatment

An estimated 0.8 radiation-related LCFs could occur in the worker population, while no cancer incidence (2×10^{-5} cancers) would be expected from hazardous chemical exposure. No noncarcinogenic health impacts are predicted. The maximum exposure index for a waste treatment worker would be 2×10^{-4}. Impacts from waste treatment under the Proposed Action were adjusted from those presented in the WM PEIS (DOE 1997); a description of this adjustment is provided in Appendix B.

WIPP Disposal Operations

Radiological impacts to the involved worker population at WIPP from disposal operations would be less than 1 LCF, and hazardous chemical impacts would be less than 0.01 cancers. No noncarcinogenic health effects would occur. External radiation doses would be the primary source of potential radiological impacts to involved workers; there would be negligible impact from intakes of radioactive material. Worker population impacts were estimated using a total of 36 involved workers (32 Waste Handling Building workers and four underground workers).

The drum vent filters prevent the release of particulates, although small quantities of radioactive gases would be released from containers. Workers would be exposed to external radiation from radioactive decay of radionuclides in the waste and receive an external dose. Worker doses are administratively limited at WIPP to 1 rem per year for the whole-body and 50 rem per year for any extremity (DOE 1995e). CH-TRU waste containers are limited to external dose rates of 200 mrem per hour at the surface of the container. The majority of routine worker doses would result from the disposal of CH-TRU waste rather than RH-TRU waste because of the greater throughput volume of CH-TRU waste and the use of RH-TRU waste remote disposal operations. Estimates of worker whole-body doses were made assuming that the worker would be exposed at 1 meter (3.3 feet) from the CH-TRU waste, 2 hours per workday, 4 workdays per week.

The range of WIPP involved worker radiological impacts were estimated assuming 25 to 35 years of exposure. Impacts to involved workers from RH-TRU waste handling were assumed to be the same or less than those from CH-TRU waste handling. This assumption is conservative because RH-TRU waste is typically handled using remote-handling equipment, workers are usually protected by radiation shielding, and stricter administrative procedures are used. The impact from handling RH-TRU waste, therefore, would be less than the impact from handling CH-TRU waste.

Workers may routinely be exposed to VOCs released from the waste containers. Worker impacts are related to the quantity of VOCs released and the ventilation rate of the area where they work. Involved workers in the Waste Handling Building were assumed to be exposed to VOC emissions from the maximum number of drums or drum-equivalents that could be stationed in the Waste Handling Building at any one time (42 CH-TRU waste drums and 3 RH-TRU waste drum equivalents). All of the drums were assumed to continuously contain concentrations of VOCs equal to the weighted maximum headspace concentrations. A low ventilation rate was assumed for the Waste Handling Building.

An involved worker underground at WIPP was assumed to be exposed to the VOCs released from a nearby panel filled with CH-TRU and RH-TRU waste containers. A low ventilation rate was assumed for the underground area. Underground workers would normally be upwind of the ventilation air that passes over the waste containers. The potential carcinogenic impacts would be greater for the individual underground worker than for a Waste Handling Building worker, but no cancer incidence would be expected (0.01 cancers). Workers were assumed to be exposed for 35 years.

Noncarcinogenic health effects also were estimated for WIPP workers who would handle waste. The initial maximum HI estimates were 2 for the Waste Handling Building worker and 6 for the underground worker, so further evaluation was conducted for those constituents that had an HI near or greater than 1: (1) carbon tetrachloride for the Waste Handling Building (HI of 2) and the underground (HI of 6); and (2) methylene chloride for the Waste Handling Building (HI of 0.9). The air concentrations to which workers would be exposed were calculated and then compared with the PELs. For the VOCs noted above, the air concentrations would be at least three orders of magnitude below the PELs, well within permissible exposure limits, so no noncarcinogenic health effects would be expected.

5.1.9.4 Storage of Excess RH-TRU Waste

Under the Proposed Action, using the conservative RH-TRU waste volume estimates of Baseline Inventory Report, Revision 3 (BIR-3), a portion of the RH-TRU waste at Hanford and ORNL would not be disposed of at WIPP. (Under more recent waste volumes projected in *The National Transuranic Waste Management Plan* (DOE 1996f), all post-1970, defense RH-TRU waste could be disposed of at WIPP [see Appendix J].) The impacts of surface storage of 39,000 cubic meters (1.4 million cubic feet) of RH-TRU waste at Hanford and 4,000 cubic meters (141,000 cubic feet) of RH-TRU waste at ORNL were evaluated. The waste was assumed to be stored in RH-TRU waste canisters packaged to meet the planning-basis WAC. Radiological impacts would result from the release of gaseous radionuclides from the waste containers. The only gaseous radionuclide identified was carbon-14 in RH-TRU waste at ORNL, and no carbon-14 or radium-226 inventories are known for Hanford RH-TRU waste. Impacts from container VOC releases were estimated using the average weighted headspace concentration from waste packaged to the planning-basis WAC.

OVERVIEW OF UNCERTAINTIES IN HUMAN HEALTH IMPACT ESTIMATES

The results of any human health assessment are conditional estimates based on multiple assumptions about exposure, toxicity, release of contaminants into the environment, human behavior patterns, and other variables. Therefore, the uncertainties accompanying the analysis should be evaluated to place these risk estimates in proper perspective. Uncertainties can be classified into three broad categories: model uncertainty, scenario uncertainty, and parameter uncertainty. Each of the SEIS-II analyses has associated uncertainties that fall into each of these categories.

Model uncertainty can result from the general limitations of mathematical models. Modeling involves trying to simulate a process that is inherently complex using a fixed and relatively small number of variables. Model uncertainty is usually estimated in the verification and validation phase of model development. Model uncertainty can also result from the inappropriate application of a model to a particular scenario (for instance, in situations for which no model has been specifically designed, and existing models must be adapted for use).

Scenario uncertainty may result from a generalized or incorrect conceptualization of a contaminant release or an exposure scenario. For example, there may be errors in the generalized assumptions concerning the amount of contaminants released, the spatial distribution of potential receptors, and the intake parameters considered for the receptors. Uncertainty is introduced because of the prospective nature of the scenarios, involving actions that may be take sometime in the future. For example, the performance of facilities not yet designed or built is unknown and is therefore based on current facilities and specifications. Scenarios do not consider major hypothetical technological advances or global changes, such as a cure for cancer, global nuclear war, or a new ice age.

Parameter uncertainty may result from sampling errors, natural variability of the parameter, or the use of generic data (data that are not site-specific). The fate and transport models used to estimated risks require large amounts of data, including meteorological measurements, hydrogeologic settings, and release parameters. Actual data are used where possible, but generic data are often substituted where site-specific data are unavailable.

The WIPP SEIS-II evaluates the absolute and relative magnitude of potential human health impacts. Evaluating the absolute magnitude of human health impacts involves estimating the actual but unknown impact. The approach taken in SEIS-II was to make assumptions and employ methods that would yield reasonably conservative absolute estimates of impacts (i.e., estimates that tend to overestimated rather than underestimate impacts) using the best available data and state-of-the-art models. Impacts estimated for the various alternatives may be compared (relative impacts). Many of the uncertainties associated with the WIPP SEIS-II impact estimates are “systematic;” that is, modeling and scenario assumptions such as the population distribution around a particular site, the inhalation rate, and the way in which a population may be exposed were applied consistently (i.e., systematically) throughout the analysis. The relative differences in impact estimates among alternatives should not be greatly affected by errors associated with systematically applied assumptions. For example, if inhalation of contaminants by the off-site population was overestimated for one alternative, it was similarly overestimated for all other alternatives.

Impacts from long-term storage of the RH-TRU waste are shown in Table 5-14. Impacts to involved workers would be less than those shown for RH-TRU waste treatment in Table 5-13. Exposure of involved workers to radiation and hazardous chemicals would be controlled to ALARA levels. Administrative controls such as worker and area monitoring, rotation of workers to reduce exposures, and standard operating procedures would be used to limit exposures.

Table 5-14
Impacts from Storage of Excess RH-TRU Waste for the Proposed Action

Impact Area	Radiological	Hazardous Chemical	
	LCFs [a]	Cancer incidence	Maximum HI
Public [b]			
Population	2E-5	3E-4	N/A
MEI	1E-9 (O)	4E-8 (O)	1E-5 (O)
Noninvolved Worker			
Population	4E-5	6E-4	N/A
Maximally Exposed Noninvolved Worker	1E-8 (O)	4E-8 (H)	1E-4 (H)

[a] The probability of an LCF occurring in the ORNL MEI or maximally exposed noninvolved worker, and the number of LCFs in the population.
[b] H = Hanford, O = ORNL

N/A = Not Applicable

5.1.10 Facility Accidents

This section describes potential consequences of facility accidents at the generator-storage sites from treatment of waste to the planning-basis WAC, at two of the generator-storage sites from waste storage after treatment, and at WIPP during waste management and disposal operations. Consequences from treatment accidents were evaluated for the six major generator-storage sites (Hanford, LANL, INEEL, SRS, RFETS, and ORNL) that would treat about 98 percent of the total CH-TRU and RH-TRU waste under the Proposed Action.

Inhalation is the dominant exposure pathway for accidental releases of radionuclides and hazardous chemicals. Radiological consequences are potentially much greater than hazardous chemical consequences and are dominated by inhalation of transuranic radionuclides. Details of the methods and assumptions used in the accident analyses and complete accident scenario descriptions are provided in Appendix G.

5.1.10.1 Waste Treatment Accidents

Three potential waste treatment accidents were evaluated under the Proposed Action; they are presented in Table 5-15. Results are presented only for accidents involving CH-TRU waste. The results from these accidents would be greater than the results for similar accidents involving RH-TRU waste because CH-TRU waste contains greater concentrations of transuranic radionuclides, which are the dominant contributors to dose from the inhalation pathway (see Tables G-23 and G-24). The potential accident consequences at the five sites that would treat the greatest volume of CH-TRU waste were evaluated in detail; these sites would be Hanford, INEEL, LANL, RFETS and SRS. Potential accident consequences at ORNL, Hanford, INEEL, and LANL were evaluated for RH-TRU waste treatment separately. Consequences at LLNL, NTS, Mound, ANL-E, and other smaller sites were not evaluated because these sites would treat relatively small quantities of CH-TRU waste. Because of the small quantities, these sites would be expected to treat this waste (treatment to WAC is required prior to transportation) in small batches (e.g., 1 to 2 drum quantities at some sites). This treatment would not be expected to result in substantial consequences (i.e., no LCFs).

Table 5-15
Treatment Accident Scenarios for the Proposed Action

Accident Scenarios	Annual Occurrence Frequency	Description
Waste Spill (Accident Scenario T1)	0.01	Drum is mispositioned causing waste to spill onto the floor.
Drum Fire (Accident Scenario T2)	1E-4	Pyrophoric material inside a drum causes drum contents to burn.
Earthquake (Accident Scenario T3)	1E-5 or less	An earthquake stronger than that for which the building was designed (beyond-design-basis earthquake) (or other natural event) collapses the roof of the building, causing drums to rupture and high efficiency particulate air (HEPA) filters to fail.

Treatment accident scenarios analyzed included a high-frequency/low-consequence operational accident expected to be applicable under any facility design, a low-frequency/high-consequence operational accident, and a low-frequency/high-consequence beyond-design-basis accident involving a building collapse. Such an accident could potentially be precipitated by an earthquake, a plane crash, or a tornado; for the purposes of analysis in SEIS-II, the accident was assumed to be an earthquake. Accident analysis information is presented in Appendix G. The accidents analyzed are believed to be representative of the spectrum of potential accidents; different or additional accidents may be analyzed in past, ongoing, or future NEPA reviews or safety analysis reports.

A beyond-design-basis earthquake was chosen as the most severe accident. Other natural disasters such as tornadoes, floods, and fires would not be expected to produce more severe consequences. While the annual occurrence frequency of a beyond-design-basis earthquake varies for DOE sites across the country (1×10^{-3} or less), the frequency of a beyond-design-basis earthquake that would result in loss of confinement and collapse the building has been estimated at 1×10^{-5} or less for purposes of these analyses. The analyses were conducted to estimate the difference in consequences among the types of waste treatment and not to make decisions regarding specific treatment sites.

Estimated radiological consequences are presented in the text as the number of LCFs in the exposed population and the probability of an LCF occurring in MEIs. Carcinogenic and noncarcinogenic consequences from hazardous chemicals, both VOCs and heavy metals, also were estimated. Carcinogenic consequences are presented as the number of cancers in the exposed population and the probability of cancer for MEIs. Noncarcinogenic consequences from exposure to VOCs and heavy metals were estimated by two different methods for the waste spill accident scenario (Accident Scenario T1) and drum fire scenario (Accident Scenario T2): IDLH-equivalent ratios and Emergency Response Planning Guideline (ERPG) ratios. The potential noncarcinogenic consequences identified by ERPG ratios would be of minor importance during a beyond-design-basis earthquake and its consequent site-operations upheaval.

In general, potential radiological consequences would be higher than hazardous chemical consequences, which are very small for most accident cases. Estimated results for members of the public, the maximally exposed noninvolved worker, and the maximally exposed involved worker are presented below and in Table 5-16. Consequences to the maximally exposed involved worker were addressed qualitatively.

Table 5-16
Radiological Consequences of Treatment Accidents for the Proposed Action [a]

Accident Scenarios		Population (Number of LCFs)	MEI (probability of an LCF)	Maximally Exposed Noninvolved Worker (probability of an LCF)
CH-TRU Waste	Waste Spill (Accident Scenario T1)	Maximum: 3E-4 (RFETS)	Maximum: 1E-7 (LANL)	Maximum: 4E-7 (Hanford)
	Drum Fire (Accident Scenario T2)	Maximum: 3E-4 (RFETS)	Maximum: 1E-7 (LANL)	Maximum: 4E-7 (Hanford)
	Earthquake (Accident Scenario T3)	Hanford: 3 INEEL: 0.1 LANL: 1 RFETS: 3 SRS: 0.2	Hanford: 1E-3 INEEL: 8E-5 LANL: 2E-3 RFETS: 2E-4 SRS: 3E-5	Hanford: 9E-3 INEEL: 0.01 LANL: 9E-3 RFETS: 5E-3 SRS: 6E-3
RH-TRU Waste	Waste Spill (Accident Scenario T1)	Maximum: 1E-8 (ORNL)	Maximum: 1E-11 (ORNL)	Maximum: 1E-11 (ORNL)
	Drum Fire (Accident Scenario T2)	Maximum: 2E-6 (ORNL)	Maximum: 2E-9 (ORNL)	Maximum: 6E-9 (INEEL)
	Earthquake (Accident Scenario T3)	Hanford: 6E-5 INEEL: 3E-6 LANL: 2E-5 ORNL: 1E-4	Hanford: 3E-8 INEEL: 1E-9 LANL: 3E-8 ORNL: 1E-7	Hanford: 2E-7 INEEL: 2E-7 LANL: 1E-7 ORNL: 3E-7

[a] The site with the greatest consequences is shown in parentheses. Complete information about accident scenarios T1 and T2 for all sites is contained in Appendix G.

Note: This table presents estimates of the consequences of accident scenarios and does not reflect the frequency (or probability) of the accident occurring.

The potential radiological consequences from RH-TRU waste treatment accidents would be the greatest at the ORNL site for all accident scenarios and receptors; however, they would be four to five orders of magnitude less than the consequences from CH-TRU waste treatment accidents.

Public

Population consequences from treatment accidents were estimated for the exposed populations around the six major treatment sites. Potential consequences to the population and MEIs at the six sites vary over a wide range because population distributions, the distances to the MEIs, and atmospheric dispersion factors differ among the sites. No LCFs would be expected in the exposed population from the waste spill or drum fire scenarios (Accident Scenarios T1 and T2, respectively), but 3 LCFs were estimated to occur due to the earthquake (Accident Scenario T3) at RFETS and Hanford. One LCF was estimated for LANL. The radiological consequences were estimated to be the highest to the MEI at LANL for all three accident scenarios. For the earthquake scenario (Accident Scenario T3), consequences to the MEI were estimated to range from a 3×10^{-5} (at SRS) to 2×10^{-3} (at LANL) probability of an LCF.

Depending on the treatment site, carcinogenic consequences from VOCs would be two to five orders of magnitude greater than consequences from heavy metals for the waste spill and earthquake scenarios (Accidents T1 and T3, respectively) (see Appendix G). Heavy metals would

account for all carcinogenic consequences from the drum fire scenario (Accident Scenario T2) because VOCs would be consumed by the fire. No cancers were estimated to occur in the exposed population from the hazardous chemical releases of any accident. The maximum probability of developing cancer would be 2×10^{-9} to the MEI from any of the accidents. The Hanford and LANL MEI could develop irreversible or severe noncarcinogenic health effects from exposure to hazardous chemicals as a result of the events in the earthquake scenario (Accident Scenario T3).

CRITICALITY

Criticality is defined as a state in which a self-sustaining nuclear chain reaction is achieved. The fissile material in the TRU waste that would be disposed of at WIPP would have to achieve a critical mass (the smallest mass of fissionable material that will support a self-sustaining nuclear chain reaction) in order to drive such a reaction. The minimum critical mass of a fissile material is the amount that can be made critical in a spherical geometry with optimum conditions. These conditions are considered incredible in the WIPP repository environment. Although TRU waste does contain fissile and fissionable material such as Pu-239, Pu-241, U-233, and U-235, DOE safety analysis reports for packaging for the TRUPACT-II (Revisions 0 and 16) and the RH-72B found that a criticality event is not a credible scenario. Indeed, the planning-basis WAC has established nuclear criticality criteria for both CH-TRU and RH-TRU waste that define the maximum allowable quantity of fissile material. These limits are defined in terms of Pu-239 fissile-gram equivalents (FGE) and include a factor allowing for two times the measurement error when the waste packages are assayed. The planning-basis WAC allows up to 200 FGE for a 55-gallon drum and 325 Pu-239 FGE for the RH-72B cask, TRUPACT-II, ten drum overpack, and standard waste box. DOE intends to revise the planning-basis WAC to allow waste transport in pipe overpacks containing up to 2,800 FGEs per TRUPACT-II. NRC has approved use of these overpacks in the TRUPACT-II container. Assumptions regarding use of these overpacks in the SEIS-II transportation analysis are included in a text box in Section A.2.1.4.

The primary difference between CH-TRU waste and RH-TRU waste is the inclusion of other radionuclides, Cs-137 and its decay product Ba-137m, Am-241, Sr-90, and Co-60. These radionuclides, present in sufficient quantities, give a TRU waste container or cask a higher surface dose rate and, thus, the need to handle the waste container or cask remotely for worker protection. However, these radionuclides cannot support self-sustaining nuclear chain reaction and are not factors when determining the potential for criticality. In general, the radionuclides that affect criticality are present in higher concentrations in CH-TRU waste than in RH-TRU waste. Therefore, criticality concerns associated with CH-TRU waste would provide bounding conditions for RH-TRU waste. Therefore, a criticality event involving RH-TRU waste is also considered incredible, although this type of accident is being further investigated.

The portion of the TRU waste Total Inventory that has a noteworthy concentration of radionuclides of concern is the RFETS plutonium residue waste. On average, a drum of RFETS plutonium residue waste would contain 8.6 curies of Pu-239 and 50.5 curies of Pu-241 per drum which represents approximately 139 FGEs in a drum. These concentrations indicate that only two drums of RFETS plutonium residue waste could be shipped in a TRUPACT-II without exceeding the 325 FGE limit for a TRUPACT-II. Other drums could be transported as long as the FGEs remained within the limits of the WAC. Proposed treatment being considered in the ***Management of Certain Plutonium Residues and Scrub Alloy Stored at the Rocky Flats Environmental Technology Site Environmental Impact Statement (Draft in Preparation)*** could also reduce the FGE concentrations in this waste. No other source of TRU waste contains higher concentrations of fissile or fissionable radionuclides. Assumptions regarding RFETS plutonium residue waste in the SEIS-II transportation analysis are included in a text box in Section A.2.1.4.

Maximally Exposed Noninvolved Worker

The maximally exposed noninvolved worker was assumed to be at the location of greatest consequence outside of the waste treatment building. The consequences to the noninvolved worker were estimated to vary over one order of magnitude across the five sites. Radiological consequences to the maximally exposed noninvolved worker would result in a 4×10^{-7} probability of an LCF from the events of the waste spill scenario (Accident Scenario T1), a 4×10^{-7} probability of an LCF from the events of the drum fire scenario (Accident Scenario T2), and up to a 0.01 probability of an LCF (at INEEL) from the beyond-design-basis earthquake (Accident Scenario T3).

No cancer incidence would be expected from the release of hazardous chemicals or metals from any of the accidents; the greatest probability of cancer would be 7×10^{-9} (see Appendix G). If the events of the earthquake scenario should occur (Accident Scenario T3), noninvolved workers at all sites would have chances of developing noncarcinogenic irreversible or severe health effects, but none of them would be life threatening. These effects would be expected from exposure to heavy metals and VOCs.

Maximally Exposed Involved Worker

No consequences to the maximally exposed involved worker would be anticipated from the events in either the waste spill or drum fire scenarios (Accident Scenarios T1 and T2, respectively). These accidents are such that involved workers would be able to evacuate immediately or would not be affected by the events. Substantial consequences would be possible from the events of the earthquake scenario (Accident Scenario T3), ranging from workers killed by debris from collapsing treatment facilities to high external radiation doses from RH-TRU waste being treated. Intakes of radionuclides, VOCs, and heavy metals would also be likely.

5.1.10.2 Excess RH-TRU Waste Storage Accident

Under the Proposed Action, excess RH-TRU waste could potentially be stored at Hanford and ORNL, regardless of whether waste is consolidated. (New estimates indicate all post-1970, defense RH-TRU waste could be disposed of at WIPP; see Appendix J.)

Should excess RH-TRU waste need to be stored, lower transuranic radionuclide activity in RH-TRU waste (lower PE-Ci levels, see Table G-23 and Table G-24), lower RH-TRU waste volume, more robust waste containers for RH-TRU waste, and presumably more robust construction of RH-TRU waste storage facilities (thick concrete walls for external radiation shielding) would all combine to limit potential consequences from excess RH-TRU waste accidents.

Operational accidents involving storage of excess RH-TRU waste were estimated to have no or negligible consequences, so only the bounding case accident, a beyond-design-basis earthquake (with an assumed annual accident frequency of 1×10^{-5} or less), was examined. The beyond-design-basis earthquake was assumed to collapse the RH-TRU waste storage facility. Twenty-five percent of the RH-TRU waste canisters were assumed to be breached, and 5 percent of the contents in the drums inside were assumed to spill. The respirable airborne fraction of the spilled contents was assumed to be 5×10^{-6}, and 50 percent of this fraction was assumed to escape the debris of the storage structure. In subsequent facility accident sections for the other alternatives, this accident scenario is designated Accident Scenario S3.

Radiological consequences would be much greater than hazardous chemical consequences and are shown in Table 5-17. Consequences would be greater at Hanford than at ORNL in all cases. Exposed populations could experience 3 x 10^{-3} (at ORNL) to 0.9 (at Hanford) LCFs, the MEI could have up to a 5 x 10^{-4} probability of an LCF (at Hanford), and the maximally exposed noninvolved worker could have up to a 3 x 10^{-3} probability of an LCF (Hanford).

Table 5-17
Radiological Consequences of an Excess RH-TRU Waste Storage Accident for the Proposed Action

Accident Scenarios	Population (number of LCFs)	MEI (probability of an LCF)	Maximally Exposed Noninvolved Worker (probability of an LCF)
Earthquake (Accident Scenario S3)	Hanford: 0.9 ORNL: 3E-3	Hanford: 5E-4 ORNL: 3E-6	Hanford: 3E-3 ORNL: 6E-6

Note: This table presents estimates of the consequences of accident scenarios and does not reflect the frequency (or probability) of the accident occurring.

No cancer would be expected to occur from hazardous chemical exposure. The highest estimate of cancer in the population would be 1 x 10^{-4} from VOCs and 4 x 10^{-7} from heavy metals near Hanford. The MEI near Hanford would have the highest probability of cancer occurring, 7 x 10^{-8} from exposure to VOCs and 2 x 10^{-10} from exposure to heavy metals. The maximally exposed noninvolved worker would be located at Hanford as well, with a 4 x 10^{-7} probability of cancer from exposure to VOCs and a 2 x 10^{-9} probability of cancer from exposure to heavy metals. No noncarcinogenic consequences would be expected.

Catastrophic destruction of the RH-TRU waste storage facility due to an earthquake could result in death or serious injury to the maximally exposed involved worker, principally from falling accident debris and radiation doses.

5.1.10.3 WIPP Disposal Accidents

Eight potential accidents at WIPP during disposal operations were evaluated; they are shown in Table 5-18. Six of the accidents involve only CH-TRU waste (Accident Scenarios W1 through W5 and W7), one involves only RH-TRU waste (Accident Scenario W8), and one was evaluated for consequences from both CH-TRU and RH-TRU waste (Accident Scenario W6).

Potential radiological consequences to the public and maximally exposed noninvolved worker are substantially higher than hazardous chemical consequences, which are very small for most accident cases. Estimated results for members of the public, the maximally exposed noninvolved worker, and the maximally exposed involved worker are presented below and in Table 5-19.

Public

Population consequences from WIPP disposal accidents were estimated for the 22.5 degree sector west of the site, which includes the City of Carlsbad. The population in this sector is 25,629 and would be affected greater than any other section in the surrounding 80-kilometer (50-mile) region.

Table 5-18
WIPP Disposal Accident Scenarios for the Proposed Action

Accident Scenarios	Annual Occurrence Frequency	Description
Drums Drop, Lid Failure in Waste Handling Building (Accident Scenario W1)	0.01	A package of drums is dropped in the Waste Handling Building, a drum on top of the package falls and its lid seal fails.
Drum Drop, Puncture, Lid Failure in Waste Handling Building (Accident Scenario W2)	0.01	Forklift strikes and punctures drums on lower level of stack in the Waste Handling Building. A drum on the upper level falls and the lid seal fails.
Drums Drop, Lid Failure in Underground (Accident Scenario W3)	0.01	Same as accident W1, but it occurs in the underground.
Drum Drop, Puncture, Lid Failure in Underground (Accident Scenario W4)	0.01	Same as accident W2, but it occurs in the underground.
Container Fire (Accident Scenario W5)	1E-4 (<8 PE-Ci) <1E-6 (>8 PE-Ci)	Contents of a drum in an underground disposal room spontaneously combusts prior to panel closure.
Hoist Failure (Accident Scenario W6)	<1E-6	Waste hoist braking system fails and fully loaded hoist falls to the bottom of shaft. Both CH-TRU and RH-TRU waste loads were evaluated.
Roof Fall (Accident Scenario W7)	0.01, Panel 1 <1E-6, other panels	A portion of a disposal room roof falls prior to panel closure, crushing drums and causing container breaches.
RH-TRU Canister Breach (Accident Scenario W8)	1E-4 to 1E-6	RH-TRU waste canister is breached during Waste Handling Building operations.

Table 5-19
Radiological Consequences of WIPP Disposal Accident Scenarios for the Proposed Action

Accident Scenarios	Population (LCFs)	MEI (probability of LCF)	Maximally Exposed Noninvolved Worker (probability of LCF)	Maximally Exposed Involved Worker (probability of LCF)
Drop, Lid Failure in Waste Handling Building (Accident Scenario W1)	9E-3	1E-4	1E-4	0.03
Drop, Puncture Lid Failure in Waste Handling Building (Accident Scenario W2)	0.02	2E-4	2E-4	0.06
Drop, Lid Failure in Underground (Accident Scenario W3)	9E-3	1E-4	1E-4	0.03
Drop, Puncture, Lid Failure in Underground (Accident Scenario W4)	0.02	2E-4	2E-4	0.06
Container Fire (Accident Scenario W5)	0.3	4E-3	3E-3	N/A
Hoist Failure (CH-TRU, RH-TRU) (Accident Scenario W6)	CH-TRU: 5 RH-TRU: 2	CH-TRU: 0.08 RH-TRU: 0.03	CH-TRU: 0.06 RH-TRU: 0.02	See Footnote a
Roof Fall (Accident Scenario W7)	0.2	2E-3	2E-3	See Footnote a
RH-TRU Canister Breach (Accident Scenario W8)	5E-3	7E-5	5E-5	0

[a] These impacts could range from negligible (workers not present, or warned of the falling hoist and evacuated) to catastrophic (all workers in the immediate vicinity killed by accident debris)

N/A = Not Applicable

Note: This table presents estimates of the consequences of accident scenarios and does not reflect the frequency (or probability) of the accident occurring.

Consequences to the MEI were evaluated at the point of closest public access to the DOE Exclusive Use Area boundary and the least atmosphere dispersion of facility exhaust ventilation air, which would be the location of maximum consequence. This point was 300 meters (990 feet) south of the Exhaust Filter Building. No credit was taken for high-efficiency particulate air (HEPA) filtration of estimated accident releases from either the Exhaust Filter Building or the Waste Handling Building.

Radiological consequences from accidents would be higher than consequences from hazardous chemicals. The accident with the largest potential radiological consequence to the population and the MEI would be the failure of a fully loaded waste hoist (Accident Scenario W6), which has a 95th percentile probability of occurrence of 4.5×10^{-7} per year (Greenfield and Sargent 1995). Up to 5 LCFs could occur in the exposed population, and the MEI could experience a 0.08 probability of an LCF. The roof fall accident (Accident Scenario W7) would result in the highest potential carcinogenic hazardous chemical consequence, with an estimated 1×10^{-6} cancers occurring in the exposed population and an estimated 2×10^{-8} probability of cancer for the MEI. No fatalities due to toxicological effects would be expected, with the MEI estimated to inhale no more than of 2×10^{-3} percent of an IDLH-equivalent intake of any hazardous chemical under either the hoist failure or roof fall accidents. However, based on ERPG ratios, an extreme circumstance where the hoist fails while carrying a full load of drums, all with bounding methylene chloride concentrations and beryllium content, might result in serious health consequences. High concentrations of 1,1,2,2-tetrachloroethane and heavy metals could also produce serious, although not life-threatening, consequences from a hoist failure or roof fall accident.

Maximally Exposed Noninvolved Worker

The maximally exposed noninvolved worker at WIPP was assumed to be located at the location of least atmospheric dispersion, 300 meters (990 feet) south of the Exhaust Filter Building, which is the same location as the MEI. The stack that exhausts the underground ventilation is elevated and, as a result, the location of least plume dispersion is some distance from the release point. Radiological consequences shown in Table 5-19 may be slightly lower than those for the MEI because of the small difference in the radiation dose-to-LCF conversion factors for workers and members of the public. The hazardous chemical consequences would be identical to those of the MEI.

Maximally Exposed Involved Worker

The potentially highest consequences to an involved worker would be underground, from failure of a fully loaded waste hoist (Accident Scenario W6) or roof fall (Accident Scenario W7). These consequences could range from negligible (workers not present or warned of the falling hoist and evacuated) to catastrophic (all workers in the immediate vicinity killed by accident debris). Four workers would be expected to be routinely involved in underground operations and potentially at risk from these accidents.

Radiological consequences of accidents to the maximally exposed involved worker from noncatastrophic accidents are shown in Table 5-19. The consequences from the drop, puncture, and lid failure accidents (Accident Scenarios W2 and W4), would be a 0.06 probability of an LCF. The highest hazardous chemical carcinogenic consequences to an involved worker were estimated to be from the accidental breach of three drums, with a 3×10^{-7} probability of cancer due to

inhalation of VOCs. No fatalities due to toxicological effects would be expected, with the highest ratio of the IDLH-equivalent intake being 5×10^{-4} for the breach of three drums (Accident Scenarios W2 and W4).

Based on ERPG analyses and conservative exposure assumptions, the involved worker might experience a life-threatening effect from exposures to high concentrations of methylene chloride from drum breaches (Accident Scenarios W1 through W4); irreversible, but not life-threatening consequences from high 1,1,2,2-tetrachloroethane and methylene chloride concentrations.

5.1.11 Industrial Safety

Under the Proposed Action, four fatalities would occur during the waste treatment period from industrial accidents at all treatment sites. This result was found by adjusting the physical-hazard fatality estimate of the WM PEIS.

At WIPP, the management and operating contractor has been awarded the star status in the DOE Voluntary Protection Program. This star status recognizes as "exemplary" the safety culture at the WIPP site. It is reciprocal with OSHA's Voluntary Protection Program star recognition. This star status indicates that the WIPP work force tends to have far fewer accidents and injuries than those at other DOE facilities. Regardless, estimates of potential industrial safety impacts to workers for proposed operations at WIPP were made using the average DOE occupational injury/illness and fatality rates shown in Table 5-20. DOE as a whole is well below the national average with respect to accident rates. DOE's average total recordable case (TRC) rate for 1988 to 1992 was 0.032 accidents per worker-year. The average TRC rate for private industry from 1983 to 1992 was 0.084 accidents per worker-year.

Table 5-20
Average Occupational Injury/Illness and Fatality Rates (per worker-year) [a]

Category	All Labor Categories (Operations)		Construction Worker (Excavation and Decommissioning)	
	Total Injury/Illness	Fatalities	Total Injury/Illness	Fatalities
DOE and Contractors [b]	0.032	3.2E-5	0.062	1.1E-4
Private Industry [c]	0.084	9.7E-5	0.13	3.4E-4

[a] Taken from DOE 1995b, Vol 2, Table F-4-7
[b] 1988-1992 averages from DOE (U.S. Department of Energy), 1993, "Occupational Injury and Property Damage Summary, January-March 1993," DOE/EH/015370-H2, March, Washington, D.C.
[c] 1983-1992 averages from NSC (National Safety Council), 1993, "Accident Facts," Itasca, New York.

For the purpose of estimating impacts, salt excavation activities were considered to be equivalent to construction activities, which have a higher rate of injury and illness than all other labor categories combined, and all other WIPP operations activities were considered jointly under all labor categories.

During the 35-year WIPP disposal operations period under the Proposed Action, the work force was assumed to remain constant at 1,095. Salt excavation would be undertaken by a crew of 10, with the remaining 1,085 workers employed in other operational activities. At the conclusion of

operations, there would be a 10-year decommissioning period. For the purpose of estimating industrial safety impacts during this 10-year period, it was assumed that the work force would decrease by 10 percent each year and that half of the work force would be involved in decommissioning activities equivalent to construction activities.

The estimated number of injuries/illnesses and fatalities among workers from operations, excavation, and decommissioning are shown in Table 5-21. Fewer than two worker fatalities would be expected from industrial-related occurrences during the 45 years of operations and decommissioning. Oversight and inspections by the Mining Safety and Health Administration (MSHA) and adherence to OSHA regulations would likely reduce actual occurrences below these estimated values.

Table 5-21
Industrial Safety Impacts from Operations and Decommissioning of WIPP for the Proposed Action

Years	Injury/Illness			Fatalities		
	Construction	Operations	Total	Construction	Operations	Total
Operations 1998-2033	22	1,225	1,247	0.035	1.2	1.3
Decommissioning 2033-2043	187	96	283	0.3	0.1	0.4
Operations & Decommissioning Total	209	1,321	1,530	0.4	1.3	1.7

5.1.12 Long-Term Performance

This section presents the potential impacts associated with the long-term performance of the WIPP repository for the Proposed Action evaluated for the 10,000-year period after the site is closed. These impacts were estimated based on computer simulations that predicted radionuclide and heavy metal releases from TRU waste in the repository under undisturbed and disturbed conditions.

The conceptual and computational models used in the analyses were based on models and tools used by the Department in current regulatory compliance analyses. The WIPP Program has been conducting analyses of long-term performance as a part of regulatory compliance with RCRA regulations and certification under 40 CFR Part 191 and 40 CFR Part 194. Although SEIS-II does not directly address these regulatory requirements, the scenarios analyzed in SEIS-II were chosen to represent the types of analyses that are being conducted for regulatory compliance applications.

The results presented here are consistent with those in the *Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant* (DOE 1996g). SEIS-II results were determined using the same computer codes employed for the regulatory compliance documents.

Analysis of the long-term impacts of WIPP was previously performed in SEIS-I. New analyses were deemed necessary in SEIS-II for the following reasons: (1) the current alternatives are different from those analyzed for SEIS-I in 1990, (2) the waste volumes and inventories for the Proposed Action and action alternatives are different from those used for SEIS-I in 1990, (3) new

data have been collected for use in performance assessment models since 1990, and (4) substantial improvements have been made in the WIPP performance assessment approaches and computational tools (DOE 1996g). A discussion of developments since SEIS-I is provided in Appendix H.

For the purposes of analyses, the CH-TRU waste volumes were assumed to be 168,500 cubic meters (5.95 million cubic feet). Because of limits on the amount of RH-TRU waste currently permitted at WIPP, only 7,080 cubic meters (250,000 cubic feet) of RH-TRU waste were assumed to be emplaced with the Proposed Action. The radionuclide inventory was adjusted, using the ratio derived from these volume changes, to 5.8×10^6 Ci in CH-TRU waste and 4.3×10^5 Ci in RH-TRU waste. Additional information on waste volumes and inventories is presented in Chapter 3 and in Appendix A.

The approach for SEIS-II had five major elements:

- The computational approach used a selected set of computer simulations rather than a full probabilistic analysis to represent the broad range of impacts that could be expected from long-term undisturbed and disturbed performance.
- Performance analyses were conducted using both median and 75th percentile values for model parameters.
- Both undisturbed and disturbed (i.e., human intrusion) conditions were analyzed.
- Numerical evaluation of performance was done using codes developed for WIPP.
- Results for long-term performance assessment were provided for the first 10,000 years after repository closure.

Though many parameters are employed for long-term performance assessment, only a small number have a potential impact on the estimate of contaminants released. Some of the important parameters include the solubility of contaminants in the waste form, sorption of contaminants on salt, hydraulic conductivity of the salt beds near the repository, volume and pressure of the hypothetical brine reservoir in the event of an intrusion, and underground water travel times.

Estimates were made for expected performance conditions and for degraded performance. Expected performance was analyzed using median values of the statistical distributions that describe the input parameters for the full probabilistic analysis required by 40 CFR Part 194. Degraded performance was analyzed using the 75th percentile parameter values from the statistical distributions of the input parameters.

The use of median parameter values means that the results would be expected to fall in the middle of the results produced from a full probabilistic analysis. A model run using all median parameters would not yield the same result as the median output. Use of the 75th percentile parameter values would produce a conservative result, yielding model results that should fall in the upper tail of a full probabilistic analysis. They are not expected to yield higher impacts than the highest impact calculated from a full probabilistic analysis.

Both undisturbed and disturbed repository conditions were considered. Undisturbed conditions examined repository performance for 10,000 years post-closure with no human intrusion. Two release and exposure scenarios for disturbed conditions were considered:

- Surface release caused by drilling into the repository. Drilling into the repository may cause a direct release of drill cuttings containing waste material to the land surface, exposing individuals involved in the drilling processes to radioactive material and heavy metals.

- Drilling through the repository and into a pressurized brine reservoir in the Castile Formation below the repository. This condition may allow brine in the pressurized reservoir to come into contact with waste in the repository. The brine could then move further up the borehole to the more permeable units lying above the repository horizon, like the Culebra Dolomite in the Rustler Formation, allowing migration of radionuclides and heavy metals into the accessible environment. Impacts of two different mining conditions were considered: partial mining that would remove all potash reserves outside the Land Withdrawal Area and full mining that would remove all potash reserves both outside and inside the Land Withdrawal Area.

Drilling intrusions analyzed in SEIS-I considered a family farm scenario that was assumed to be located 500 meters (1,640 feet) from the discarded drill cuttings. Currently, no farms exist near the WIPP site. Agricultural use of land in the region is limited mainly to cattle grazing due to poor soil conditions, a limited supply of stock-potable water, and no source of water for farming. Even if water were available, saline soil conditions make farming unlikely. For these reasons, the family farm scenario was not considered in SEIS-II analyses of drilling intrusion impacts.

The four cases below were analyzed for the Proposed Action:

- Case 1 considered undisturbed repository conditions. Median parameter values were used for input variables where probability distributions have been defined.

- Case 2 considered disturbed conditions resulting from a borehole assumed to pass through the repository and intercept a pressurized brine reservoir in the Castile Formation. Median parameters values were used for input variables where probability distributions have been defined.

- Case 3 was the same as Case 1 but used 75th percentile parameter values for input variables where probability distributions have been defined.

- Case 4 was the same as Case 2 but used 75th percentile parameter values for input variables where probability distributions have been defined.

5.1.12.1 Impacts of Undisturbed Conditions

The NUclide Transport System (NUTS) code was used to simulate radionuclide and heavy metal transport using the time-varying brine and gas flow fields computed by BRAGFLO. The two-dimensional modeling domain extended 23.3 kilometers (14.5 miles) laterally in each direction from the edge of the repository and vertically from the Castile Formation below the repository to the ground surface.

The extent of radionuclide and heavy metal (lead, mercury, beryllium, and cadmium) migration for undisturbed conditions at 10,000 years after closure for Case 3 (using 75th percentile parameter values) over the model domain is presented in Figure 5-1. Case 3 resulted in slightly more extensive migration than Case 1. Figure 5-1 shows the locations in the modeled region where the

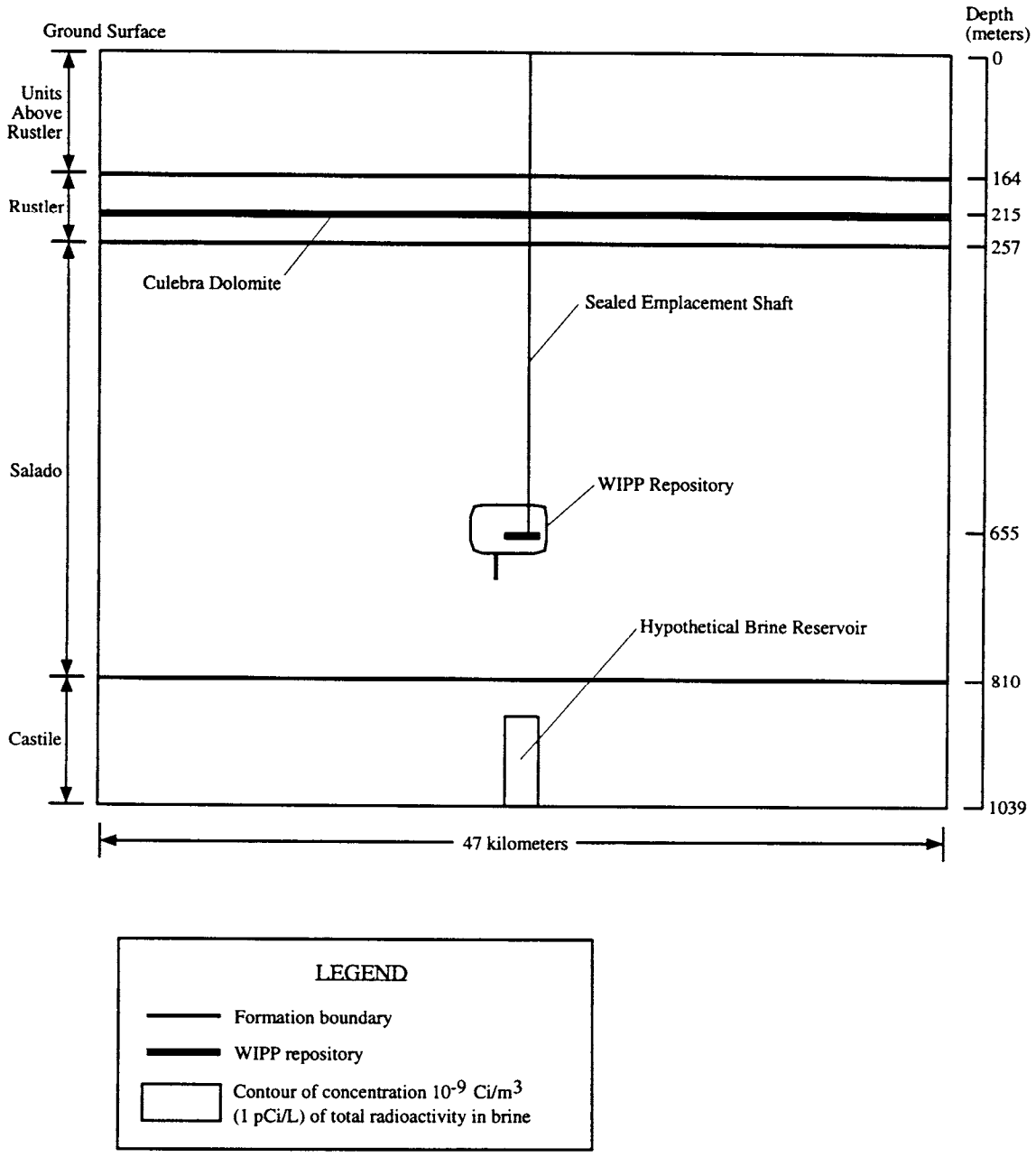


Figure 5-1
Extent of Radionuclide Migration at 10,000 Years with Undisturbed Conditions Using 75th Percentile Parameter Values (Case 3) for the Proposed Action

concentration of total radionuclide activity in the brine, summed over 30 radionuclides, is equal to 1 picocurie (pCi) per liter (1 x 10^{-9} Ci per cubic meter). Total heavy metal concentration of one part per billion (1 x 10^{-3} milligrams per cubic meter) showed approximately the same extent of migration from the repository as the one pCi per liter level of total radionuclide activity concentration.

The total vertical scale of the modeled region is 1,039 meters (3,409 feet). The horizontal extent of the modeled region represented in Figure 5-1 is approximately 47 kilometers (29 miles). The vertical scale is greatly exaggerated so the extent of vertical migration can be seen in the figure. For the Proposed Action, total radionuclide activity concentrations of one pCi per liter would extend about 60 meters (200 feet) below the repository, 40 meters (130 feet) above the repository, and about 1,900 meters (6,200 feet) laterally from the south edge of the repository.

Analysis of undisturbed repository conditions (Cases 1 and 3) during the first 10,000 years showed that no radionuclides or heavy metals would be released to the Culebra Dolomite. No total radionuclide activity concentrations greater than 1 pCi per liter or heavy metal concentrations greater than 1 part per billion would be found beyond the 5-kilometer (3-mile) subsurface lateral boundary. There would be no release to the accessible environment and therefore no human health impact. Additional information is provided in Appendix H.

5.1.12.2 Impacts of Disturbed Conditions

This section presents the impacts of two exposure scenarios evaluated for the disturbed conditions of the Proposed Action.

Surface Release Caused by Drilling into the Repository

In this scenario, a drilling operation penetrates a waste panel in the repository. The analysis here is for only one event, although DOE recognizes that during a 10,000-year period more than one borehole could penetrate the repository. The drilling operation was assumed to bring waste originating in the repository to the land surface through a number of physical processes. These processes create cuttings (created by the cutting action of the drill bit), cavings (waste introduced into the borehole is eroded as drilling fluids move up or down the borehole), and spallings (waste and brine caused by the movement of repository gas to the low pressure conditions existing in the borehole). The generation of spallings in a borehole could be affected by very high-pressure repository conditions, causing waste to move into the borehole under blowout or direct gas erosion conditions.

The quantity of waste released would be dependent on repository gas- and brine-pressure conditions and the overall waste characteristics (primarily porosity and permeability) at the time the repository is breached by the borehole.[1] The relationship of repository pressure and these release processes has been quantified and provides the basis for calculations of direct waste releases for the CUTTINGS_S computer code. The values of brine and gas pressure in the repository and the permeability of the waste used to determine the release process under this model were obtained from the fluid flow simulations performed with the BRAGFLO computer code. Simulated brine and gas pressures were derived for undisturbed conditions calculated for Cases 1 and 3 (the

[1] For a multiple-intrusion scenario, the maximum impact would be seen in the first intrusion; less material would be released at any one borehole following the first intrusion because gas pressure would likely dissipate after the first intrusion.

pressure history in the repository is the same until the time of intrusion, so the pressure encountered for any given intrusion time is represented by the analagous undisturbed case). The calculations of direct waste releases for the simulated BRAGFLO conditions were carried out using the CUTTINGS_S code.

Human health impacts would be limited to individuals involved in the drilling operation. No population impacts were calculated because only small amounts of radioactive material would be brought to the surface, remain in a wet, relatively nondispersable form, and would remain localized. Impacts were estimated for two types of exposed individuals:

- A member of a drilling crew directly involved in the borehole drilling. This individual was assumed to be exposed to external radiation from materials at the drill head and in the drill cutting pond and to inadvertently ingest 100 milligrams per day of borehole material. This individual was assumed to be exposed for 168 hours (8 hours per day for a 21-day working period).

- A well-site geologist involved in the periodic examination of cuttings generated by the drilling process. This individual would be exposed to external radiation through the direct handling of an exhumed fragment of waste. The concentration of radionuclides in the exhumed waste fragment was assumed to be the emplacement concentration decayed to the time of intrusion. The geologist was assumed to pick up a cylindrical waste fragment 5 centimeters (2 inches) in radius with a volume of 524 cubic centimeters (32 cubic inches). An exposure time of one hour was assumed.

The drilling intrusions were timed to maximize the estimated health impacts to exposed individuals. The earliest time that intrusion could occur was assumed to be 100 years after repository closure, the end of the active institutional control period. Because results of BRAGFLO calculations showed a steady increase in brine pressures in the repository (approximately 5 to 14 MPa) over the initial 2,000 years following repository closure, the potential impact of repository pressure conditions on the release of materials up the borehole was examined. Radiation dose calculations were performed for intrusions 100, 200, 300, 400, 500, 800, 1,200, and 2,000 years after closure. These calculations showed that an intrusion event at 400 years after closure for Case 2 (median parameter values) and an intrusion event at 300 years after closure for Case 4 (75th percentile parameter values) would lead to the greatest potential health impacts. As a result, impact analysis of the drilling intrusion under the Proposed Action (and all other action alternatives) assumed the intrusion occurred at these respective times. Additional information on this analysis is presented in Appendix H.

The estimated activity of radionuclides released to the ground surface during the drilling event for Case 2 (median parameter values) was 3.1 Ci, consisting mainly of Am-241, Pu-239, and Pu-238. For Case 4 (75th percentile parameter values), the release was 4.5 Ci, again consisting mainly of Am-241, Pu-239, and Pu-238. Heavy metal releases were 24 kilograms (53 pounds) of lead and 2 kilograms (4 pounds) of mercury for Case 2 and 31 kilograms (68 pounds) of lead and 3 kilograms (7 pounds) of mercury for Case 4.

Radiological impacts to a member of the drilling crew for Case 2 (median parameter values) would be a 2×10^{-4} probability of an LCF. For Case 4 (75th percentile parameter values), the impacts

would be slightly higher with a 4×10^{-4} probability of an LCF. The impact in these cases would be primarily due to the inadvertent ingestion of drill cuttings. The radionuclide with the greatest impact contribution (approximately 97 percent) was Am-241.

The drilling crew member may also ingest heavy metals (lead, beryllium, cadmium, and mercury) in the drill cuttings. There would be a 2.2×10^{-8} probability of a cancer incidence to the drill crew member from heavy metal ingestion. There would be no noncarcinogenic impacts expected from the ingestion of the metals because all hazard indices would be much less than one. Impacts of exposure to VOCs were not analyzed (see Appendix H) but were expected to be bounded by impacts of VOC exposure for WIPP disposal accidents (see Appendix G). There would be a 3×10^{-7} probability of a cancer incidence. Some short-term toxicological effects from inhalation of VOCs could occur (see Appendix G) under these assumptions.

Radiological impacts to a well-site geologist from external radiation exposure for Case 2 (median parameter values) would be a 3×10^{-9} probability of an LCF from CH-TRU waste and a 9×10^{-10} probability of an LCF from RH-TRU waste. For Case 4 (75th percentile parameter values), the radiological impacts would be a 3×10^{-9} probability of an LCF from CH-TRU waste and a 3×10^{-9} probability of an LCF from RH-TRU waste. The major dose contributors from CH-TRU waste were Am-241 and U-234, while Sr-90 and Cs-137 were major dose contributors from RH-TRU waste.

Drilling Through the Repository into a Pressurized Brine Reservoir

In this scenario, a borehole would be drilled through the repository into a pressurized brine reservoir, introducing a high permeability (relative to the permeability of the intact salt) groundwater pathway from the repository to the Culebra Dolomite. Contaminants could migrate up the borehole and move laterally through the Culebra Dolomite.

Because current drilling practices are to plug all deep boreholes in the Delaware Basin (Thompson et al. 1996), it was assumed for SEIS-II analyses that all deep intrusion boreholes would be plugged. Boreholes were assumed to have two low permeability concrete plugs that would degrade after 200 years. Additional information on the hydrologic properties of the plugged borehole are given in Appendix H.

The extent of radionuclide migration at 10,000 years after closure for Case 4 (75th percentile parameter values) is presented schematically in Figure 5-2. Total radionuclide activity concentrations of one pCi per liter are shown. Simulations showed radionuclides migrated upward and downward into the borehole and penetrated into rocks directly in contact with the borehole for a limited distance. For Case 4 at 10,000 years, migration extends upward into the Culebra Dolomite. Migration also extends downward in the borehole (for both Cases 2 and 4) to the Castile Formation and into the brine reservoir. This would occur after the initial pressure in the pressurized brine pocket dissipates and equilibrates with pressures in the repository and overlying units penetrated by the borehole. A total heavy metal concentration of one part per billion (1×10^{-3} milligrams per cubic meter) showed approximately the same extent of migration from the repository as the one pCi per liter level of total radionuclide activity concentration. Predicted brine pressures and additional modeling information is provided in Appendix H.

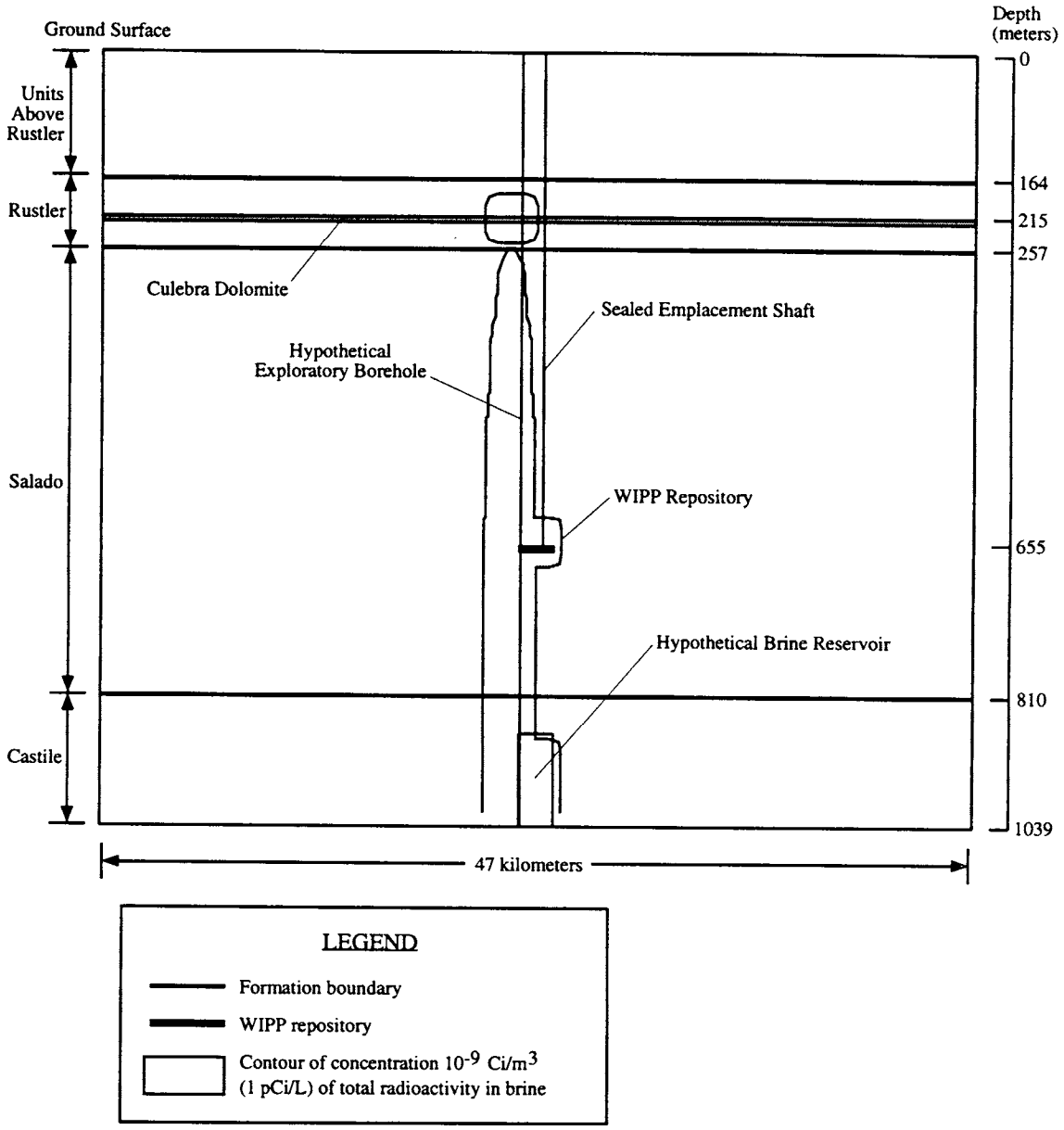


Figure 5-2
Extent of Radionuclide Migration at 10,000 Years with Disturbed Conditions Using 75th Percentile Parameter Values (Case 4) for the Proposed Action

THE PROPOSED ACTION AND THE ADDITIONAL INVENTORY

During the public comment period that followed publication of the Draft SEIS-II, several stakeholders requested that the Additional Inventory be included in the Proposed Action. The Additional Inventory, as defined in Chapter 2, is largely TRU waste disposed of prior to 1970 by near surface burial at sites throughout the DOE Complex. The Department currently has no plans to excavate all of this waste and would do so only following Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) or RCRA investigations and possibly following additional NEPA review. The Additional Inventory, therefore, is still not a part of the Proposed Action. This text box, though, is provided to assist those wishing a general understanding of the impacts of this waste under four scenarios. The scenarios and their impacts follow:

All Additional Inventory would be left as currently stored or buried: The impacts for this scenario would be similar to the Additional Inventory impacts of No Action Alternative 2. Because no treatment or transportation of this waste would occur, no treatment or transportation impacts would occur. Most of the waste would remain buried, so no biological, cultural, infrastructure, water, land use, or socioeconomic impacts would occur due to the Additional Inventory. Approximately 13 LCFs are estimated at the sites where the waste is currently stored should it be left in place for 10,000 years and no intrusion occur. The principal sites where these impacts are estimated are INEEL (at 7.6 LCFs) and LANL (at 5.6). For additional results, see the Additional Waste columns on each table of Section 5.6, later in this chapter.

All Additional Inventory would be excavated, treated to WAC, and stored where currently located for approximately 70 years: During the 70 years, the Department, would look for a disposal solution. The impacts for this scenario would be very similar to the Additional Inventory storage impacts presented for treatment and storage under Action Alternative 1. No transportation would occur, so no transportation impacts are expected. No impacts to the public or noninvolved workers from treatment and storage of this waste are expected. Involved worker impacts would include up to 2 LCFs for treatment and 3 LCFs for storage. For additional results, see the Additional Waste columns of Section 5.2, immediately following this section.

All Additional Inventory would be excavated, shipped to six thermal treatment facilities, treated, and then stored for approximately 70 years: During the 70 years, the Department, would look for a disposal solution. The impacts for this scenario would be very similar to the Additional Inventory impacts for treatment and storage under Action Alternative 2A and No Action Alternative 1A. As noted in No Action Alternative 1A, transportation only to treatment facilities would result in no estimated accidents, injuries, or fatalities. No impacts to the public or noninvolved workers due to storage would be expected; about 1 LCF would be expected to involved workers. For treatment, 1 LCF is estimated for the involved workers. For additional results, see the Additional Waste columns concerning Action Alternative 2A and No Action Alternative 1A on each table of Sections 5.3 and 5.5.

All Additional Inventory would be excavated, shipped to four thermal treatment facilities, treated, and then stored for 70 years: During the 70 years, the Department, Congress, and the nation would look for a disposal solution. The impacts for this scenario would be very similar to the Additional Inventory impacts presented for treatment and storage under Action Alternative 2B and No Action Alternative 1B. As noted in No Action Alternative 1B, transportation for treatment would result in two transportation accidents resulting in two injuries. An estimated 1 LCF each would be expected to the population and involved workers due to treatment. No impacts due to storage would be expected to the population or noninvolved workers; about 1 LCF would be expected to the involved workers. For additional results, see the Additional Waste columns concerning Action Alternative 2B and No Action Alternative 1B on each table of Sections 5.3 and 5.5.

THE WM PEIS PREFERRED ALTERNATIVE

For the purposes of analysis in the Draft SEIS-II Proposed Action, the Department assumed that TRU waste treatment would be partially consolidated in accordance with the Decentralized Alternative of the WM PEIS. Since publication of the Draft SEIS-II, the Final WM PEIS identified a preferred alternative which was a combination of the WM PEIS Alternatives. If TRU waste were treated at the locations identified in the WM PEIS preferred alternative, there would be a slight impact on the analysis set forth in SEIS-II, although there would be no changes in health and other impacts. The modifications to impacts, should the Department select the WM PEIS preferred alternative, are shown below.

RH-TRU waste from SRS would be consolidated at ORNL before disposal at WIPP.

For purposes of analysis of this potential consolidation, the waste volumes used for the WM PEIS have been used. The inventory used for other SEIS-II analyses shows no RH-TRU waste at SRS. The WM PEIS inventory includes up to 21 cubic meters [700 cubic feet] of RH-TRU waste, nearly all of it to be generated during the next 20 years. The number of shipments of RH-TRU waste involved would be approximately 23. The additional miles would also be small because SRS is east of ORNL (the waste would travel west, then south to WIPP). The overall additional impacts (when added to the impacts of the 7,957 shipments in the Basic Inventory) would be small (0.03 additional accidents, 0.03 additional injuries, and 0.004 additional fatalities). Radiological impacts to the occupational population would be 1×10^{-4} LCFs and for nonoccupational populations would be 3×10^{-3} LCFs. (If this waste went directly to WIPP, the impacts would be the same as those presented for the Proposed Action.)

The CH-TRU waste at ORNL would be consolidated at SRS before disposal at WIPP.

A total of 1,700 cubic meters (60,000 cubic feet) or 251 shipments of waste would be transported. The additional transportation would result in 0.1 additional accidents, 0.1 additional injuries, and no additional fatalities. Additional radiological impacts to the occupational population would be 4×10^{-4} LCFs. The radiological impacts to the public would decrease slightly (by 5×10^{-5} LCFs) because of a difference in accident rates along the roadways. The number of shipments would be spread over 35 years, averaging less than 10 shipments per year. Because CH-TRU waste at SRS would be transported to WIPP during the same 35-year period, only small additional impacts to the cost and risk from storage would occur.

Some RFETS CH-TRU waste would be shipped to INEEL for treatment before shipment to WIPP.

Recent estimates are that about 1,000 cubic meters (35,000 cubic feet) of RH-TRU waste would be shipped to INEEL for treatment before shipment to WIPP. For purposes of analysis, the number of shipments was conservatively estimated at 250, though would probably be lower. Additional impacts from this transportation would be 0.25 additional accidents, 0.06 additional injuries, and 0.1 additional fatalities.

Waste from small generator sites (with the exception of Sandia) would be shipped directly to WIPP instead of being consolidated before shipment to WIPP. Waste from Sandia would be consolidated at LANL.

Approximately 25 shipments of CH-TRU waste at the small generator sites would be directly shipped to WIPP under either the WM PEIS preferred alternative (or scenarios where there is no consolidation), and the number of shipments from the potential consolidation sites would probably be reduced. Although routes from the small generator sites have not been proposed, impacts from the additional miles, if any, to be traveled by so few shipments (when compared to the 29,766 shipments for the total campaign) would be so small that the results from the total shipping campaign would not change. For RH-TRU waste, 958 shipments (931 of them from Battelle Columbus Laboratory) would transport waste directly to WIPP, and there would be a one for one reduction in the number of RH-TRU waste shipments from the consolidation sites (because RH-TRU waste would not be repackaged at the potential consolidation sites). The mileage when shipping directly to WIPP would be nearly the same as when first consolidating that waste. Therefore, it is unlikely that there would be additional impacts during the shipping campaign.. Therefore, it is unlikely that there would be additional impacts during the shipping campaign.

Impacts of radionuclide and heavy metals migration were evaluated for Case 4 (75th percentile parameter values) since a release of contaminants into the Culebra Dolomite was indicated for this case only. The potential human health impacts were evaluated at a stock well assumed to be located 3 kilometers (2 miles) downgradient from the borehole (point of intrusion). It was assumed that this well would provide contaminated water to stock ponds used by cattle. Direct uses by humans were not considered because of the high salinity of groundwater in the area. Beef cattle were assumed to drink 50 liters (13.2 gallons) of water per day from the well. Beef from cattle using this water was assumed to be consumed by an individual such as a cattle rancher at a rate of 42 kilograms (93 pounds) annually (about 4 ounces per day) over a 70-year lifetime.

Both partial potash mining (mining only outside the Land Withdrawal Area boundary) and full potash mining (mining inside and outside the Land Withdrawal Area boundary only) conditions were evaluated. Partial mining would result in a 7×10^{-28} probability of an LCF to an individual ingesting beef from cattle using the water from this well over the individual's lifetime. Full mining would result in a 4×10^{-41} probability of an LCF to this individual. The probability of a cancer incidence from ingesting heavy metals would not exceed 3×10^{-27} and 3×10^{-37} for partial and full mining, respectively. No noncarcinogenic impacts would be expected because the estimated hazard index would not exceed 1×10^{-20}. Additional information is presented in Appendix H.

5.1.12.3 Long-Term Storage of Excess RH-TRU Waste

DOE may continue to store excess defense RH-TRU waste beyond the WIPP authorized disposal capacity at Hanford and ORNL under the Proposed Action. (The most recent estimates indicate all post-1970, defense RH-TRU waste can be disposed of at WIPP; see Appendix J.)

Continued storage of excess waste, should it be necessary, would result in less than two worker deaths for each 100 years of storage. If institutional control were lost and the waste were released, it would be expected to cause about 0.02 aggregate deaths over a 10,000-year period, assuming current population distributions.

5.2 IMPACTS OF ACTION ALTERNATIVE 1

This section describes the environmental impacts associated with implementation of Action Alternative 1. This alternative proposes treating waste to WAC[1], consolidating the waste at the same sites discussed under the Proposed Action, and disposing of the waste at WIPP. In addition to the Basic Inventory, WIPP would accept nearly all other DOE-controlled waste (i.e., the Additional Inventory without the polychlorinated biphenyl (PCB) commingled waste). The treatment time frame would remain 35 years. Though additional waste would be treated under this alternative, the treatment time period would be three and a half times that assessed in the WM PEIS. The total consolidated volume of waste to be treated under this alternative is 312,000 cubic meters (11 million cubic feet) (see Tables 3-2 and 3-3), less than three times the 110,000 cubic meters (3.9 million cubic feet) assessed in the WM PEIS. The WIPP operational time frame would extend to the year 2158 (160 years) so that the additional waste could be emplaced. (See Section 5.2.13 for discussion of how the impacts change should the operational time frame be reduced to 60 years.)

[1] For purposes of analysis, the current planning-basis WAC was used.

FACTORS TO CONSIDER IN COMBINING ALTERNATIVES

When considering whether to implement a combination of alternatives, it is important to identify factors that lead to differences in impacts. How impacts change in relation to several factors is examined here.

WASTE VOLUME: In general, impacts (particularly treatment and transportation impacts) vary directly according to waste volume. The greater the waste volume, the greater the impacts. Preliminary figures from recent data indicate that projected waste volumes through 2033 could be lower than BIR-3 projections through 2022 by about 30,000 cubic meters for CH-TRU waste (which translates to a decrease of about 34,000 cubic meters from SEIS-II 2033 CH-TRU waste projections) and about 20,000 cubic meters for RH-TRU waste (which translates to a decrease of about 25,000 cubic meters from the SEIS-II 2033 RH-TRU waste projections). The accuracy of these projections depends, in part, on remediation decisions that would be made in the future and the effect these decisions could have on the timing of TRU waste generation. Much of this potential decrease could result if DOE were to decide to leave some of the instrumentation and machinery related to facilities with high radiation levels (such as instrument trees, and mixer pumps in the Hanford high-level waste tanks, which are projected to be RH-TRU waste when removed from the tanks) in place at those facilities until the facilities themselves are remediated, thus resulting in reduced TRU waste generation through 2033. This decrease would not affect waste volumes proposed to be disposed of under the Proposed Action and would not affect the analysis of the impacts of that action, except that impacts from storage of excess RH-TRU waste would decrease. The waste volumes for alternatives that involve disposing of all of the waste have changed (see Appendix J). Impacts directly related to waste volume may be reduced for the action alternatives that consider disposing of all DOE TRU waste, including impacts from transportation and routine waste treatment operations. The need to dispose of a lower volume of TRU waste could reduce operational time periods for the alternatives by about 50 (Alternative 2) to about 75 years (Alternative 3) and would also reduce the land area above the repository that would be impacted by closure activities. The annual probability of an accident occurring would be the same, but the number of years during which an accident could occur would be reduced. The lower waste volumes would not affect the ability of WIPP to isolate the waste once it is disposed of.

WASTE TREATMENT: Health impacts related to treatment for both workers and the public in the short-term increase as the complexity of waste treatment increases. Treatment to planning-basis WAC has the least impact, followed by shred and grout treatment, with thermal treatment having the highest treatment related impacts of the three treatment alternatives examined.

WASTE MANAGMENT: The long-term impacts of disposal at WIPP are lower than the long-term impacts of the waste storage. This is particularly true when loss of institutional control of the waste is assumed. Also, industrial accidents could lead to substantial impacts if waste were stored for long time periods.

WASTE TYPE (CH-TRU or RH-TRU): Transportation of RH-TRU waste would have relatively greater transportation impacts than CH-TRU waste primarily because of the smaller volume of RH-TRU waste per shipment which increases the number of shipments required to move the RH-TRU waste. Otherwise, on a per unit volume basis, the impacts from treatment and storage of RH-TRU waste are less than those for CH-TRU waste.

TRANSPORTATION MODE: Overall, regular rail transportation would have the least impacts, truck transportation impacts would have about 2 to 3 times that of regular rail service, and dedicated rail service would be about 23 times those of regular rail transportation.

DURATION OF ALTERNATIVE: Longer durations would spread the impacts out over more generations, exposing more people to potential impacts; the risk to each population therefore, would be less. Shorter durations would expose fewer people to potential impacts, the risk to each population would be slightly higher.

As appropriate, analyses include assessment of the impacts of storage of treated TRU waste before disposal. For the purposes of this document, this storage is called lag storage. Analyses in Action Alternative 1 also include a qualitative assessment of the impacts of rail transportation. A detailed description of Action Alternative 1 is given in Section 3.2.2.

5.2.1 Land Use and Management

At the treatment sites, land use impacts under Action Alternative 1 would be the same as those under the Proposed Action. The type, size, and number of treatment and consolidation facilities needed under this alternative would be comparable to those for the Proposed Action. The Department would be able to minimize impacts to on-site land use and avoid conflicts with off-site land use plans. It also would be able to avoid sensitive or inappropriate areas, including cultural resource areas, the habitats of threatened or endangered species, wetlands, and flood plains. Before treatment facilities would be constructed, further NEPA reviews would be undertaken at a site-wide or project-specific level.

At WIPP, land use impacts on the surface during disposal operations under Action Alternative 1 would be similar to those under the Proposed Action discussed in Section 5.1.1. These impacts would be similar because the surface facilities would be the same as those for the Proposed Action. One difference from the Proposed Action would occur during the decommissioning and closure process; approximately 360 hectares (890 acres) would be affected due to an increased underground waste disposal area. This area would be included in the bermed and permanently marked area once closure was begun. Like the Proposed Action, the rest of the Land Withdrawal Area would be available to the public for nonintrusive surface activities following decommissioning and closure. Restrictions on slant drilling would continue.

5.2.2 Air Quality

At the treatment sites, the potential annual air quality impacts would not differ substantially from those presented for the Proposed Action in Section 5.1.2. The only criteria pollutant postulated to exceed 10 percent of the applicable annual regulatory standard during operation of treatment facilities would be CO at RFETS (17 percent), the same as for the Proposed Action. RFETS, LLNL, NTS, and ANL-E are in nonattainment areas for some pollutants. In nonattainment areas, activities that introduce new sources of emissions are regulated under the General Conformity Rule. In attainment areas, regulations for the PSD of ambient air quality apply. In both cases, a permit is required for sources which will result in emissions equal to or greater than the limits set by pertinent regulations. No radiological, hazardous, or toxic air pollutants would exceed 10 percent of the applicable regulatory standard (DOE 1997). Potential minor emissions of PM_{10} may occur during construction.

At WIPP, the potential annual air quality impacts under Action Alternative 1 would be the same as those anticipated under the Proposed Action. Although the increased waste disposal volume would increase the duration of disposal activities, there would be no substantial differences in the rates of pollutant emissions on an annual or short-term basis.

Potential air quality impacts due to decommissioning of WIPP under Action Alternative 1 would be similar to those anticipated under the Proposed Action. Because the waste disposal area would increase, the construction of berms and permanent markers and other decommissioning activities

would take longer, although these activities would still be within the 10-year decommissioning period. Thus, there would be no substantial difference in the rate of pollutant emissions.

5.2.3 Biological Resources

The potential impacts on biological resources at the treatment sites under Action Alternative 1 would be the same as those under the Proposed Action described in Section 5.1.3. Threatened and endangered species may be present at all of the proposed treatment sites and could potentially be impacted; however, whether there would be impacts depends on the actual location of the facility at a particular site. Site selection would be conducted following site-wide or project-level NEPA review during which such impacts would be assessed and mitigated as necessary. Endangered, threatened, or proposed species and all critical habitats would be avoided and appropriate consultation, monitoring, and mitigation measures would be undertaken as necessary. The longer treatment period proposed for Action Alternative 1 is not expected to have any additional impact to species over the life of the campaign. Analyses also determined that terrestrial wildlife species would not be affected by airborne emission from waste management or treatment facilities nor from spills of TRU waste into aquatic environments due to traffic accidents (DOE 1997).

Federally listed, threatened and endangered, and state-listed species occur in Eddy County and potentially at the WIPP, although DOE has not observed threatened, endangered, or proposed species or critical habitats at the WIPP site during surveys conducted for recent biennial environmental compliance reports. DOE recently completed a site-specific biological survey, during which no endangered, threatened, or state-listed species were identified.

At WIPP, the potential impacts on biological resources under Action Alternative 1 would be similar to those under the Proposed Action (described in Section 5.1.3) except for impacts resulting from the increased underground waste disposal area. A total of 360 hectares (890 acres) of aboveground area would be disturbed during salt pile reclamation and construction of berms and permanent markers during closure. These activities would disturb avian and small mammal habitat. These areas would be attractive after natural vegetation recolonizes.

5.2.4 Cultural Resources

At the treatment sites, the potential impacts on cultural resources are expected to be the same under Action Alternative 1 as for the Proposed Action. This is because the size and number of the facilities would be the same as those assessed for the Proposed Action. The construction and operation of TRU waste treatment facilities could adversely affect cultural resources; however, site-level cultural resource surveys would be conducted and protection measures would be established, where necessary, when specific facility construction locations are proposed (DOE 1997). These surveys would be part of site-wide or project-level NEPA reviews. Sacred sites and burials would be avoided when siting the facilities, and appropriate consultation would be undertaken during the reviews.

At WIPP, all of the surface area included under Action Alternative 1 has been inventoried for cultural resources as part of the initial survey of the 1,040-hectare (4-square mile) central WIPP site. Eleven prehistoric archaeological sites (LA14307, LA14308, LA33155, LA33156, LA33157, LA33159, LA33160, LA33163, LA33170, LA33179, and LA33180) are located in the previously surveyed areas within Sections 28 and 29, T. 22S, R. 31E. Each of these sites was evaluated by the original investigators as being potentially eligible for inclusion in the NRHP (DOE 1995c).

TRU waste shipping and operational activities at WIPP would not have an impact on these or other archaeological sites. Depending on final project design, some of these archaeological sites could be affected by closure and decommissioning-related activities. Surface ground disturbance for construction of long-term decommissioning features such as various types of markers, earthen berms, and informational centers could impact some archaeological sites.

Measures for ensuring protection of known archaeological and historic resources (or others that may be inadvertently discovered during ground-disturbing activities) are discussed in the *Waste Isolation Pilot Plant Land Management Plan* (DOE 1996a). These measures include identifying, inventorying, evaluating, and treating cultural resources under the National Historic Preservation Act of 1966. DOE will avoid, to the extent possible, sites found eligible for inclusion in the NRHP. Where avoidance is not possible, mitigation measures will be developed under the Joint Powers Agreement between DOE and the State of New Mexico.

5.2.5 Noise

Treatment facilities would probably be located in industrial areas along high-volume roadways, and, therefore, ambient noise levels would not increase substantially (DOE 1997). Sensitive receptors, however, may be impacted. Further analysis has been reserved for site-wide or project-level NEPA review (DOE 1997). Because all waste would travel to WIPP but only a portion of the waste would travel to or from each treatment facility under this alternative, the greatest impacts due to transportation noise would be near the WIPP site and are discussed below.

At WIPP, potential noise impacts under Action Alternative 1 for truck transportation and operations would be similar to those described under the Proposed Action in Section 5.1.5. This is because the throughput rate was assumed to remain the same (50 TRUPACT-IIs and eight RH-72B casks per day). The trucks would still arrive at random times throughout the day.

Unlike the Proposed Action, Action Alternative 1 examines rail transportation. All rail transportation of TRU waste destined for WIPP would travel through Carlsbad, New Mexico, to Loving, New Mexico, where it would be diverted to WIPP via a dedicated spur. Rail noise may be disruptive to certain public and private institutions. The commercial rail noise impact would result from the addition of rail cars carrying TRUPACT-IIs or RH-72Bs to existing commercial trains. A single rail car may carry up to six TRUPACT-IIs or two RH-72Bs. The noise impact would be a slight increase in the duration of propagated noise resulting from trains passing through the affected communities. The estimated impact would depend on the speed of the rail car and the total number of rail cars. Use of dedicated trains would result in increased rail traffic through Carlsbad and Loving and would be potentially more disruptive than use of commercial rail. Assuming each dedicated train contained three fully loaded rail cars, four additional trains could pass through these cities each week, averaging less than one additional train per day. Therefore, the overall noise impact would be negligible.

5.2.6 Water Resources and Infrastructure

Because the SEIS-II operations time would be three and a half times longer and the volume of waste treated less than three times higher than that anticipated under the WM PEIS, the size of the treatment facilities needed for Action Alternative 1 would be comparable, if not smaller, than those analyzed for the WM PEIS. Therefore, the incremental impacts to site infrastructure are estimated to be the same as those reported in the WM PEIS.

Although no off-site infrastructure impacts are expected to occur, proposed TRU waste activities at the treatment sites would affect on-site activities, including the capacities of on-site water, power, and wastewater systems, and on-site transportation. The impacts would be the same as those for the Proposed Action. Only Hanford would show an increase in on-site demand for wastewater that would exceed five percent of current demand (5.9 percent). Major impacts to water resources at the treatment sites would be unlikely (DOE 1997).

Minor impacts to the on-site transportation infrastructure are expected under Action Alternative 1. These impacts are a result of an increase in on-site employment of 6 percent at Hanford and INEEL and 7 percent at LANL. Impacts to the off-site transportation infrastructure are not anticipated because population increases do not exceed 5 percent (DOE 1997).

At WIPP, negligible annual infrastructure impacts would be expected under Action Alternative 1. Existing water supply and sewer capabilities and existing and planned power and roadway resources will be able to accommodate proposed disposal operations.

5.2.7 Socioeconomics

Estimated life-cycle costs and potential socioeconomic impacts for Action Alternative 1 are presented in the following subsections.

5.2.7.1 Life-Cycle Costs

Life-cycle costs under Action Alternative 1 are presented in Table 5-22 for three areas: treatment facilities, waste transport, and WIPP disposal operations. Waste treatment facility costs include construction, O&M, and D&D at the treatment sites. For the purposes of SEIS-II analyses, it was assumed that the treatment sites would process, treat, and package waste to planning-basis WAC over a period of 35 years (as in the Proposed Action, but for larger waste volumes). Correspondingly, sites with large volumes (INEEL, Hanford, and ORNL) would be required to store portions of the treated waste volumes over some or all of the 160-year disposal operations period, mainly due to RH-TRU waste throughput limitations at WIPP. The waste treatment facility life-cycle costs would be $21.39 billion (in 1994 dollars).

Table 5-22
Life-Cycle Costs for Action Alternative 1 (in millions of 1994 dollars) [a]

Cost Information	Basic Inventory			Additional Inventory			Total	Total Discounted
	CH-TRU Waste	RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU Waste	RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU and RH-TRU Waste
Treatment Facilities	8,430	3,120	11,550	8,860	980	9,840	21,390	11,860
Transport by Truck	1,200	2,690	3,890	750	270	1,020	4,910	778
Transport by Regular Rail	400	890	1,300	250	90	340	1,640	260
Transport by Dedicated Rail	2,760	6,200	8,960	1,740	620	2,360	11,320	1,790
Disposal at WIPP	10,600	2,700	13,300	11,100	250	11,350	24,650	3,680
Total Life-Cycle Cost (Truck Transport)	20,230	8,510	28,740	20,710	1,500	22,210	50,950	16,320
Total Life-Cycle Cost (Regular Rail)	19,430	6,720	26,150	20,210	1,320	21,530	47,680	15,800
Total Life-Cycle Cost (Dedicated Rail)	21,790	12,020	33,810	21,700	1,850	23,550	57,360	17,330

[a] The methods and assumptions used to estimate the various cost components are described in Appendix D. Actual totals may differ due to rounding.

Action Alternative 1 considers three waste transportation options from the treatment sites to WIPP: (1) trucks only, as in the Proposed Action, (2) trucks with maximum regular (commercial) rail service, and (3) trucks with maximum dedicated rail service. Under transportation options 2 and 3, rail routes would be used to the greatest extent practical. LANL and NTS would be the two exceptions because there are no rail routes to these sites; thus, their waste would be entirely transported by truck. Under these options, the transportation costs reflect consolidation of the waste volumes at the treatment sites and shipment of the treated volumes via truck or rail to WIPP for emplacement. The waste transport life-cycle costs would be $4.91 billion by truck, $1.64 billion by regular rail, and $11.32 billion by dedicated rail.

The WIPP life-cycle costs would be $24.65 billion. The total life-cycle costs for the Total Inventory under Action Alternative 1 would be $50.95 billion ($16.32 billion when discounted) using truck transportation, $47.68 billion ($15.80 billion when discounted) using regular rail transportation, or $57.36 billion ($17.33 billion when discounted) using dedicated rail transportation.

5.2.7.2 Economic Impacts

Treatment activities would support direct, indirect, and induced jobs. Action Alternative 1 would support approximately 22,500 annual jobs in the ROIs of the 10 major treatment sites (ANL-E, Hanford, INEEL, LANL, LLNL, Mound, NTS, ORNL, RFETS, SRS).

Within the WIPP ROI, estimates of the impacts of Action Alternative 1 on employment, income, and the production of goods and services are presented in Table 5-23. These regional impacts are estimated using an annual average project budget of $180 million per year over a 160-year period of disposal operations. During this extended period of waste emplacement operations, the WIPP facility would remain a stable federal employer in the ROI economy by providing direct employment for 1,095 project personnel annually. Indirectly, the operation of WIPP (from 1998 through 2158) would annually support 2,443 jobs in the ROI work force. Total annual WIPP-induced employment within the ROI would be 3,538.

Because the projected average annual project budget is close to historical levels, Action Alternative 1 would not be expected to result in additional use of government-provided goods or services (schools, police, fire protection, and health protection) nor require major capital investments in public infrastructure within the ROI. For this same reason, Action Alternative 1 would not be expected to impact the local real estate markets nor result in major changes in the work force population.

Table 5-23
Economic Impacts within the ROI for Action Alternative 1

Economic Effects	Total Output of Goods and Services (in millions of 1994 dollars)	Total Employment (Full- and Part-Time Jobs)	Total Labor Income (in millions of 1994 dollars)	Carlsbad Output of Goods and Services (in millions of 1994 dollars)	Carlsbad Employment (Full- and Part-Time Jobs)	Carlsbad Labor Income (in millions of 1994 dollars)
Direct – Annual	113	1,095	52	95	979	46
Indirect & Induced – Annual	204	2,443	75	172	2,185	67
Total – Annual	317	3,538	126	267	3,164	113
Total - Operations (160 years)	50,720	566,080 [a]	20,160	42,720	506,240 [a]	18,080

[a] Job-years (number of annual jobs supported multiplied by the number of years in the project).

5.2.8 Transportation

This section presents the transportation impacts for Action Alternative 1. Treatment and consolidation of TRU waste and the radionuclide and hazardous chemical concentrations in the waste are the same for truck transportation in the Proposed Action and Action Alternative 1; therefore, the differences between the transportation impacts are due solely to the increased number of shipments under Action Alternative 1. Rail transportation impacts for both regular and dedicated train options for Action Alternative 1 are presented at the end of this section.

5.2.8.1 Route Characteristics and Shipment Projections

The methods used to determine route characteristics and the number of shipments were identical to the approach as presented in Section 5.1.8.1. Table 5-24 presents the number of shipments required under Action Alternative 1. Because the consolidation and treatment of waste would be the same for the Proposed Action and Action Alternative 1, the mileage for each route would also be the same (see Table 5-5).

Table 5-24
Number of Truck Shipments to WIPP for Action Alternative 1 [a]

Waste Treatment Site	CH-TRU Waste			RH-TRU Waste		
	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total
Argonne National Laboratory - East	24	---	24	---	---	---
Hanford Site	11,562	7,167	18,729	47,156	1,651	48,807
Idaho National Engineering and Environmental Laboratory/ANL-W	4,892	6,474	11,366	3,136	711	3,847
Lawrence Livermore National Laboratory	137	---	137	---	---	---
Los Alamos National Laboratory	4,238	1,590	5,828	367	190	557
Mound Plant	50	23	73	---	---	---
Nevada Test Site	73	---	73	---	---	---
Oak Ridge National Laboratory	212	8	220	5,875	3,076	8,951
Rocky Flats Environmental Technology Site	2,102	---	2,102	---	---	---
Savannah River Site	1,893	558	2,451	---	---	---
Total	**25,183**	**15,820**	**41,003**	**56,534**	**5,628**	**62,162**

[a] The number of shipments from sites with smaller quantities can be found in Appendix E. There would be 53 CH-TRU waste shipments and 3,850 RH-TRU waste shipments. Impacts from the transportation of TRU waste to the treatment sites is small relative to the 10 major generator-storage sites above (see Appendix E).

5.2.8.2 Accidents, Injuries, Fatalities, and Pollution-Related Health Effects from Truck Transportation

The total number of accidents, injuries, and fatalities over the transportation period of 160 years for Action Alternative 1 are shown in Table 5-25. For Action Alternative 1, a total of 171 accidents, 119 injuries, and 16 traffic-related fatalities were estimated. Also shown in Table 5-25 are the estimated cancer fatalities attributed to diesel exhaust (pollution health effects).

Table 5-25
Nonradiological Impacts of Transporting
TRU Waste by Truck for Action Alternative 1

Impact	CH-TRU Waste			RH-TRU Waste			Total		
	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total
Number of Accidents	36	25	62	100	9	109	136	34	171
Number of Injuries	26	17	43	68	8	76	94	25	119
Number of Fatalities	4	2	6	9	1	10	13	3	16
Pollution Health Effects (fatalities)	0.1	0.08	0.2	0.3	0.04	0.3	0.4	0.1	0.5

These effects are based upon the total miles traveled in an urban area and 9.9×10^{-8} LCFs per kilometer (1.6×10^{-7} per mile) (Rao et al. 1982). The impacts of shipping waste from the small quantity sites to the larger treatment sites are included in Table 5-25.

5.2.8.3 Accident-Free Radiological Impacts from Truck Transportation

Accident-free radiological impacts occur during routine transportation and are the result of public and worker exposure to direct radiation at levels allowed by transportation regulations. The methods used to determine accident-free radiological impacts for Action Alternative 1 were identical to those described for the Proposed Action.

Table 5-26 presents a summary of the accident-free population radiological impacts for Action Alternative 1. Approximately 0.7 occupational LCFs and 10.5 nonoccupational LCFs would be expected in the exposed population groups. The accident-free radiological impacts of shipping waste from the small quantity sites to the larger treatment sites to consolidate TRU waste are included in the results in Table 5-26.

Table 5-26
Aggregate Accident-Free Population Radiological Impacts
from Truck Transportation for Action Alternative 1 (LCFs) [a]

Exposure Category	CH-TRU Waste			RH-TRU Waste			Total		
	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total
Occupational	0.2	0.2	0.4	0.3	0.03	0.3	0.5	0.2	0.7
Nonoccupational									
Stops	1.7	1.1	2.8	6.3	0.7	7.0	8.0	1.8	9.8
Sharing Route	0.09	0.06	0.2	0.4	0.04	0.4	0.5	0.1	0.6
Along Route	0.04	0.02	0.06	0.1	0.02	0.1	0.1	0.04	0.2
Nonoccupational Total	1.8	1.2	3.0	6.8	0.7	7.5	8.6	1.9	10.5

[a] Exposure during stops is based upon 50 individuals exposed at 20 meters. Stop time, in hours, is based upon 0.011d where d is the distance traveled in kilometers. These parameters are built into the RADTRAN code but substantially overestimate exposures from WIPP shipments. Because WIPP shipments would use two-driver teams (eliminating the need for overnight stops to sleep) and because the shipments would stop at sites chosen, in part, for their lack of population, the actual impacts from stops would be much lower.

Table 5-27 summarizes the impacts to MEIs who might be exposed to radiation because of traffic jams, lifestyles, or occupations. The discussion in Section 5.1.8.3 presents the methods used to determine the impacts presented in Table 5-27. The state vehicle inspector was estimated to have the highest potential impact with an 8.6×10^{-3} probability of an LCF.

Table 5-27
Radiological Impacts to MEIs from Truck Transportation for Action Alternative 1 (Probability of an LCF)

Individual	CH-TRU Waste	RH-TRU Waste	Total
Stuck in traffic next to shipment	2.5E-6	5.0E-6	7.5E-6
Departure Inspector	4.4E-4	5.5E-3	5.9E-3
State Vehicle Inspector	1.5E-3	7.1E-3	8.6E-3
Residing adjacent to access route	1.5E-4	6.0E-4	7.5E-4
Rest stop employee	1.0E-4	3.0E-4	4.0E-4

5.2.8.4 Radiological Impacts from Truck Transportation Accidents

Two types of analyses were conducted for SEIS-II radiological impacts from accidents. The first type of analysis determined the radiological impact from accidents during transportation from each of the 10 treatment sites to WIPP. This analysis took into account eight different severities of accidents, the number of miles from each site, and the number of shipments. The methods used were the same as those presented in Section 5.1.8.4.

The results of the analyses for route-specific accidents for the entire shipping campaign are presented in Table 5-28. The aggregate radiological impact was estimated to be 0.8 LCF.

Table 5-28
Aggregate Radiological Population Impacts from Truck Transportation Accidents for Action Alternative 1 (LCFs)

	CH-TRU Waste			RH-TRU Waste			Total		
Originating Site	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total
Argonne National Laboratory-East	4.0E-4	---	4.0E-4	---	---	---	4.0E-4	---	4.0E-4
Hanford Site	0.3	0.2	0.5	0.06	2.0E-3	0.07	0.4	0.2	0.6
Idaho National Engineering and Environmental Laboratory & Argonne National Laboratory – West	0.07	0.09	0.2	2.5E-3	5.0E-4	3.0E-3	0.07	0.09	0.2
Lawrence Livermore National Laboratory	1.5E-3	---	1.5E-3	---	---	---	1.5E-3	---	1.5E-3
Los Alamos National Laboratory	3.0E-3	1.0E-3	4.0E-3	1.5E-5	5.0E-6	2.0E-5	3.0E-3	1.0E-3	4.0E-3
Mound Plant	1.0E-3	0	1.0E-3	---	---	---	1.0E-3	---	1.0E-3
Nevada Test Site	5.0E-4	0	5.0E-4	---	---	---	5.0E-4	---	5.0E-4
Oak Ridge National Laboratory	2.5E-3	5.0E-4	3.0E-3	4.5E-3	2.5E-3	7.0E-3	7.0E-3	3.0E-3	0.01
Rocky Flats Environmental Technology Site	7.0E-3	---	7.0E-3	---	---	---	7.0E-3	---	7.0E-3
Savannah River Site	0.02	6.0E-3	0.03	---	---	---	0.02	6.0E-3	0.03
Total LCFs							**0.5**	**0.3**	**0.8**

The second type of analysis was an assessment of four conservative, bounding accident scenarios: two involving the breach of a TRUPACT-II, and two involving the breach of an RH-72B. Methods of estimating impacts from bounding case accidents are presented in Appendix E and Section 5.1.8.4. For Action Alternative 1, the potential radiological impacts from the bounding case accidents would be the same as those presented for the Proposed Action in Section 5.1.8.4. For both alternatives, TRU waste would be treated to planning-basis WAC.

5.2.8.5 Hazardous Chemical Impacts from Severe Truck Transportation Accidents

As with the Proposed Action, the hazardous chemical releases from a severe accident would present negligible hazard to the exposed population. Though the inventory for Action Alternative 1 is larger than that for the Proposed Action, the concentration of VOCs and metals in each TRUPACT-II or RH-72B would be the same. Hazardous chemical impacts from accidents would be the same as those presented for the Proposed Action in Table 5-10.

5.2.8.6 Impacts from Rail Transportation

This section presents a summary of potential impacts due to transportation by both regular and dedicated rail service. Rail service would be used to the fullest extent practical (called maximum rail), whereas truck transportation would be used only for the two sites with no rail service, LANL and NTS. SEIS-II rail impacts were determined by adjusting the SEIS-II impacts from truck transportation presented earlier in this section. Overall, these adjustments were based on the similarities and differences between the two transportation modes based on models presented in RADTRAN (Neuhauser and Kanipe 1992) and truck and rail accident statistics (Saricks and Kviteck 1994). The similarities and differences are presented in Appendix E. Some key differences are noted below:

- Overall, rail cars move slower than trucks. When vehicles move slower, those individuals living or traveling along a route are exposed for longer periods of time.

- Six TRUPACT-IIs would be put on each rail car instead of the three transported per truck. Two RH-72Bs would be put on each rail car instead of the one transported per truck.

- Each train can include many rail cars. For the purpose of SEIS-II analyses, it was assumed that a train transporting TRU waste would include three rail cars loaded with TRUPACT-IIs or RH-72Bs. For dedicated rail service, it was assumed that each train would only have the three rail cars. For regular rail service, it was assumed that the three rail cars of TRU waste would be included in a train of 70 rail cars (the average number of cars in regular rail service trains).

- When a train stops at a rail yard, there typically are other rail cars there. These other rail cars provide shielding for the potential radiation coming from TRU waste packaging.

- While many people would share a roadway with a truck transporting TRU waste, very few people would travel along a rail route at the same time as a train transporting TRU waste.

These differences result in the following adjustments to truck transportation results:

- The slower average train speed would increase the radiation dose to individuals living along rail routes by 1.5 times over that for individuals living along truck routes.

- When a shipment stops, the individual dose would be one-tenth of the dose to individuals near a stopped truck. This difference is due to the shielding provided by the other rail cars when the shipment stops in a railyard.

- When these two factors are considered together, accident-free radiological impacts are greatly reduced for rail transportation compared to truck transportation. Accident-free radiological impacts from truck or rail transportation were dominated by radiation doses received at stops.

Rail accident statistics typically include the number of trains and the number of accidents and fatalities. The statistics do not typically include information concerning the number of fatalities per rail car. For the purpose of SEIS-II analyses, it is important to understand the number of accidents and fatalities per rail car, because a commercial train has the same probability of being in an accident whether it contains rail cars with TRU waste or not. The standard method of calculating the number of accidents and fatalities per commercial train is to divide the number of accidents or fatalities per train by the average number of rail cars per train, which is 70. Therefore, when a train of 70 cars is in an accident that results in one death, that fatality would count as 1/70th of a fatality for each rail car. If that train included three rail cars of TRU waste, 3/70ths of that fatality would be apportioned to rail cars of TRU waste.

There are no statistics on the average number of cars in dedicated trains; as a result, making such adjustments becomes more difficult. The assumption for SEIS-II is that each dedicated train would only have three rail cars carrying TRU waste. Should a dedicated train be involved in an accident that results in a fatality, that fatality would be apportioned as 1/5 a fatality for each rail car. This number could be changed a great deal, though, by increasing the number of rail cars per train.

Differences in impacts between regular and dedicated rail service would be primarily due to the differences in apportioning fatalities to rail cars. For SEIS-II, it was estimated that the fatality rate for dedicated rail would be 14 times greater than for regular rail.

Table 5-29 presents the impacts of transportation by regular and dedicated rail for Action Alternative 1. The impacts presented in this table represent three rail cars of TRU waste in either regular or dedicated rail transport. Further details on the estimation of rail impacts can be found in Appendix E.

Radiological impacts from rail transportation accidents were estimated relative to impacts presented for truck transportation accidents. As described under Action Alternative 1, two types of analyses were conducted for SEIS-II radiological impacts due to accidents. The first estimated impacts over the entire shipping campaign and the second estimated impacts from four bounding case accidents.

Table 5-29
Impacts from Rail Transportation
for Action Alternative 1

Aggregate Traffic-Related Fatalities	
Regular Rail	8
Dedicated Rail	112
Aggregate Accident-Free Radiological Impacts (LCFs)	
CH-TRU Waste	
Occupational	0.02
Nonoccupational	
Stops	0.3
Sharing Route	1.6E-3
Along Route	0.09
Nonoccupational Total	0.4
RH-TRU Waste	
Occupational	0.01
Nonoccupational	
Stops	0.8
Sharing Route	3.9E-3
Along Route	0.2
Nonoccupational Total	1.1
Total CH-TRU and RH-TRU Waste	
Occupational	0.03
Nonoccupational	
Stops	1.2
Sharing Route	5.5E-3
Along Route	0.3
Nonoccupational Total	1.5
Aggregate Radiological Impacts from Rail Transportation Accidents (LCFs)	
CH-TRU Waste	0.7
RH-TRU Waste	0.08
Total CH-TRU and RH-TRU Waste	0.8

For the first analysis, the impacts were estimated based on the number of shipments, the accident frequency for each route, and the eight accident severity categories presented in RADTRAN. Because the number of miles traveled are similar between truck and rail and the rail car accident frequency is less than the truck accident frequency, it was conservatively estimated that the aggregate radiological impacts for rail transportation would be the same as those reported for truck transportation.

The estimation of radiological impacts for bounding truck accidents was done assuming that only one TRUPACT-II or RH-72B would fail in an impact event. The basis for this assumption was Fischer et al. (1987), which states that impact with a hard target, such as a bridge abutment, could potentially breach one container per shipment. To breach the container, though, it must strike a hard target head on.

For rail shipments, it was assumed that each train would include three rail cars of TRU waste. Each rail car would carry six TRUPACT-IIs or two RH-72Bs. It was also assumed that for the bounding case accidents two TRUPACT-IIs or RH-72Bs could potentially be breached. The accidents would be derailments where two rail cars would strike bridge abutments on either side of the tracks. Although other TRUPACT-IIs or RH-72B casks might experience impact forces, it was

assumed that the forces would be insufficient to breach the containers. The estimated population doses would be dominated by inhalation contributions (initial or from resuspension). The impacts are presented below:

- For the accident with the conservative inventory in two breached TRUPACT-IIs, the total population dose would result in 32 LCFs in the exposed population. The estimated maximum individual dose would result in a 0.12 probability of a cancer fatality.
- For the accident with a conservative inventory in two breached RH-72Bs, the total population dose would result in 32 LCFs in the exposure population. The estimated maximum individual dose would result in a 0.12 probability of a cancer fatality.
- For the accident with average concentrations of radionuclides in two breached TRUPACT-IIs, approximately 6 LCFs in the exposed population would be expected. The estimated maximum individual dose would result in a 0.08 probability of a cancer fatality.
- For the accident with average concentrations of radionuclides in two breached RH-72Bs, the total population dose would result in an expectation of 0.08 LCF in the population. The estimated maximum individual dose would result in a 1.4×10^{-4} probability of a cancer fatality.

As in the case for truck transportation, there would be negligible impacts from hazardous chemical releases in a rail transportation severe accident.

5.2.9 Human Health Impacts from Waste Treatment, Storage, and Disposal Operations

This section presents human health impacts to the public, noninvolved workers, and involved workers from waste treatment, lag storage, and waste disposal operations under Action Alternative 1. The methods and assumptions used were similar to those used for the Proposed Action and described in Section 5.1.9, except that the inventory to be disposed of would include the Total Inventory (except for the PCB-commingled waste).

Impacts from waste treatment were adjusted from those presented in the WM PEIS, and a description of this adjustment is provided in Appendix B. Action Alternative 1 also includes analysis of potential impacts from TRU waste in lag storage (waste that would be treated and stored awaiting shipment to WIPP for disposal). Lag storage impact estimates were made assuming the waste would be at the lag storage site for the same lifetime exposure periods as for WIPP disposal operations: 70 years for an MEI, 35 years for the surrounding population, and 35 years for noninvolved and involved workers. The shorter exposure time for the population reflects population turnover resulting from deaths, immigration, and emigration. Appendix F provides additional information on the methods used to determine the impacts from lag storage and WIPP disposal operations.

5.2.9.1 Public

Impacts to the populations and to the MEIs under Action Alternative 1 are presented in this section; results are presented in Table 5-30. Impacts from waste treatment, lag storage, and WIPP disposal operations are presented separately because different populations and individuals would be impacted by these activities. Waste treatment and lag storage would take place at multiple DOE sites but not WIPP, while disposal operations would take place only at WIPP. Population impacts

were estimated for those members of the public residing within 80 kilometers (50 miles) of all treatment sites, all lag storage sites, and at WIPP. The impacts to the MEIs from waste treatment and lag storage are presented for the highest individual waste treatment sites, while the MEI from disposal operations is near the WIPP site. See Chapter 3 for additional information on where treatment and storage would occur under Action Alternative 1.

Table 5-30
Lifetime Human Health Impacts to the Public from Waste Treatment, Lag Storage, and WIPP Disposal Operations for Action Alternative 1

	Waste Treatment Impacts		Lag Storage Impacts [a]		WIPP Disposal Operations Impacts	
Category	Radiological (LCF) [b]	Hazardous Chemical (Cancer Incidence)	Radiological (LCF) [b]	Hazardous Chemical (Cancer Incidence)	Radiological (LCF) [b]	Hazardous Chemical (Cancer Incidence) [c]
MEI [d, e]						
Basic Inventory						
CH-TRU Waste	1E-9 (R)	2E-12 (X)	2E-6 (O)	6E-8 (L)	3E-7	1E-8
RH-TRU Waste	6E-11 (L)	2E-11 (O)	1E-9 (O)	5E-8 (O)	8E-10	2E-9
Total Waste	1E-9 (R)	2E-11 (O)	2E-6 (O)	6E-8 (L)	3E-7	1E-8
Total Inventory						
CH-TRU Waste	1E-9 (R)	2E-12 (X)	2E-6 (O)	1E-7 (L)	5E-7	2E-8
RH-TRU Waste	1E-10 (L)	3E-11 (O)	2E-9 (O)	7E-8 (O)	7E-10	2E-9
Total Waste	1E-9 (R)	3E-11 (O)	2E-6 (O)	1E-7 (L)	5E-7	2E-8
Population [d]						
Basic Inventory						
CH-TRU Waste	1E-4	1E-7	1E-2	2E-3	2E-4	2E-5
RH-TRU Waste	1E-6	4E-7	3E-5	4E-4	1E-6	9E-7
Total Waste	1E-4	4E-7	1E-2	2E-3	2E-4	2E-5
Total Inventory						
CH-TRU Waste	2E-4	1E-7	1E-2	2E-3	3E-4	2E-5
RH-TRU Waste	2E-6	5E-7	4E-5	5E-4	9E-7	9E-7
Total Waste	2E-4	6E-7	1E-2	3E-3	3E-4	2E-5
Aggregate Total	2E-4	6E-7	1E-2	5E-3	4E-4	3E-5

[a] These sites would have the maximum impacts.
[b] The probability of an LCF occurring to the MEI, and the number of LCFs in the population.
[c] If a panel full of CH-TRU waste remained open during the entire 70-year lifetime of the MEI and VOCs were released at a constant rate, the MEI lifetime risk from the CH-TRU waste would be 5E-8.
[d] The MEI and populations evaluated for treatment, storage, and operations impacts are different.
[e] R = RFETS, L = LANL, O = ORNL, X = LLNL

Waste Treatment

No LCFs (2×10^{-4} LCFs) would be expected in the total population around the waste treatment sites, and no cancer incidence (6×10^{-7} cancers) would be expected in the total population from hazardous chemical exposure. The MEI would be at RFETS for radiological impacts (1×10^{-9} probability of an LCF) and at ORNL for hazardous chemical impacts (3×10^{-11} probability of a cancer incidence). No noncarcinogenic health effects would occur because the maximum HI for the MEI would be 4×10^{-10}, and no health effect is predicted unless the HI is 1 or higher.

Lag Storage

No LCFs (1×10^{-2} LCFs) would be expected in the total population around the lag storage sites, and no cancer incidence (3×10^{-3} cancers) would be expected in the total population from hazardous chemical exposure. The MEI would be at ORNL for radiological impacts (2×10^{-6} probability of an LCF) and at LANL for hazardous chemical impacts (1×10^{-7} probability

of a cancer incidence). No noncarcinogenic health effects are predicted. The maximum HI for the MEI would be 6×10^{-4}, and no health effect is predicted unless the HI is 1 or higher.

The aggregate total indicated in Table 5-30 refers to the impacts to the public expected over the entire operational period under Action Alternative 1. Lag storage impact estimates conservatively assume that the lag storage period is equivalent to the disposal operations period, which is estimated to be 42 years for CH-TRU waste and 160 years for RH-TRU waste. No LCFs (1×10^{-2} LCFs) or cancer incidence (5×10^{-3} cancers) would be expected over the several generations that would be exposed to the small potential routine releases of radioactive or hazardous materials under incident-free operations.

WIPP Disposal Operations

No LCFs (3×10^{-4} LCFs) would be expected in the population around WIPP from radiation exposure, or cancer incidence (2×10^{-5} cancers) would be expected in the population from hazardous chemical exposure.

The MEI was assumed to be located at the Land Withdrawal Area boundary, the closest point at which an individual could reside. The MEI would have a 5×10^{-7} probability of an LCF from radiation exposure and a 2×10^{-8} probability of a cancer incidence from hazardous chemical exposure. No noncarcinogenic health effects are predicted. The maximum HI for the MEI was estimated to be 7×10^{-5}, and no health effect is predicted unless the HI is 1 or higher.

The aggregate total indicated in Table 5-30 refers to the impacts to the public expected over the entire operational period. The operations period for the disposal of the Total Inventory is expected to be 42 years for CH-TRU waste and 160 years for RH-TRU waste. Under Action Alternative 1, no LCFs (4×10^{-4} LCFs) or cancer incidence (3×10^{-5} cancers) would be expected over the several generations of exposure to the estimated releases.

5.2.9.2 Noninvolved Workers

Impacts to the noninvolved worker population and the maximally exposed noninvolved worker under Action Alternative 1 are presented in this section; results are presented in Table 5-31. A noninvolved worker is an employee who works at a site but is not directly involved in the treatment, storage, handling, or disposal of waste. Impacts from waste treatment, lag storage, and WIPP disposal operations are presented separately because different noninvolved worker populations and individuals would be impacted by these activities. Waste treatment and lag storage would take place at multiple DOE sites but would not include WIPP. Disposal operations would take place only at WIPP. The impacts to the maximally exposed noninvolved worker from waste treatment and lag storage are presented for the highest individual waste treatment sites, while the maximally exposed noninvolved worker from disposal operations was assumed to work at the WIPP location where emissions have the least atmospheric dispersion and thus the greatest potential impact. This location was assumed to be 200 meters (660 feet) east of the exhaust filter building. The maximum ground-level concentrations of any airborne contamination would be expected at this location.

Table 5-31
Lifetime Human Health Impacts to Noninvolved Workers from Waste Treatment, Lag Storage, and WIPP Disposal Operations for Action Alternative 1

Category	Waste Treatment Impacts		Lag Storage Impacts		WIPP Disposal Operations Impacts	
	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence) [b]
Maximally Exposed Noninvolved Worker [c, d]						
Basic Inventory						
CH-TRU Waste	3E-9 (R)	6E-12 (X)	8E-6 (O)	2E-7 (I)	2E-7	5E-8
RH-TRU Waste	3E-11 (L)	1E-10 (O)	1E-8 (O)	4E-8 (H)	2E-9	4E-9
Total Waste	3E-9 (R)	1E-10 (O)	8E-6 (O)	2E-7 (I)	2E-7	5E-8
Total Inventory						
CH-TRU Waste	8E-9 (R)	6E-12 (X)	8E-6 (O)	5E-7 (I)	4E-7	9E-8
RH-TRU Waste	5E-11 (L)	2E-10 (O)	4E-9 (O)	4E-8 (H)	2E-9	4E-10
Total Waste	8E-9 (R)	2E-10 (O)	8E-6 (O)	5E-7 (I)	4E-7	9E-8
Population Noninvolved Worker [c]						
Basic Inventory						
CH-TRU Waste	6E-6	2E-8	3E-2	4E-3	2E-4	5E-5
RH-TRU Waste	7E-8	1E-7	6E-5	7E-4	2E-6	4E-6
Total Waste	6E-6	1E-7	3E-2	5E-3	2E-4	5E-5
Total Inventory						
CH-TRU Waste	8E-6	3E-8	4E-2	9E-3	4E-4	1E-4
RH-TRU Waste	1E-7	2E-7	9E-5	8E-4	2E-6	4E-7
Total Waste	8E-6	2E-7	4E-2	5E-3	4E-4	1E-4
Aggregate Total	8E-6	2E-7	0.05	0.01	5E-4	1E-4

[a] The probability of an LCF occurring to the maximally exposed noninvolved worker and the number of LCFs in the population.
[b] If a panel full of CH-TRU waste remained open during the entire 70-year lifetime of the MEI and VOCs were released at a constant rate, the noninvolved worker lifetime risk from CH-TRU waste would be 5E-8.
[c] The noninvolved workers considered for treatment impacts and operations impacts are different.
[d] R = RFETS, L = LANL, O = ORNL, X = LLNL, I = INEEL, H = Hanford

Waste Treatment

No LCFs (8×10^{-6} LCFs) or cancer incidence (2×10^{-7} cancers) would be expected in the total noninvolved worker population around the waste treatment sites. The maximally exposed noninvolved worker would be at RFETS for radiological impacts (8×10^{-9} probability of an LCF) and at ORNL for hazardous chemical impacts (2×10^{-10} probability of a cancer incidence). No noncarcinogenic health effects are predicted. The maximum HI for the maximally exposed noninvolved worker would be 3×10^{-9}, and no health effect is predicted unless the HI is 1 or higher.

Lag Storage

Radiological impacts from lag storage would be somewhat greater than nonradiological impacts to noninvolved workers under Action Alternative 1. No LCFs would be expected in the total noninvolved worker population at the lag storage sites (4×10^{-2} LCFs), and no cancer incidence (5×10^{-3} cancers) would be expected in the total noninvolved worker population from hazardous chemical exposure. The maximally exposed noninvolved worker would be at ORNL for radiological impacts (8×10^{-6} probability of an LCF) and at INEEL for hazardous chemical impacts (5×10^{-7} probability of a cancer incidence). No noncarcinogenic health effects would occur; the maximum HI for any maximally exposed noninvolved worker would be 4×10^{-3}.

The aggregate total indicated in Table 5-31 refers to the impacts to noninvolved worker population at the lag storage sites expected over the entire operational period under Action Alternative 1. Lag storage impact estimates conservatively assume that the lag storage period is equivalent to the disposal operations period, which is estimated to be 42 years for CH-TRU waste and 160 years for RH-TRU waste. No LCFs (0.05 LCFs) or cancer incidence (0.01 cancers) would be expected in the several generations that would be exposed to the small potential routine releases of radioactive or hazardous materials under incident-free operations.

WIPP Disposal Operations

No LCFs would be expected in the WIPP noninvolved worker population from radiation exposure (4×10^{-4} LCFs). VOC release estimates were the same as for the public. No cancer incidence (1×10^{-4} cancers) would be expected in the noninvolved worker population from hazardous chemical exposure. All 1,095 WIPP employees were assumed to be exposed at the same level as the maximally exposed noninvolved worker.

The maximally exposed noninvolved worker would have a 4×10^{-7} probability of an LCF from radiation exposure, and a 9×10^{-8} probability of a cancer incidence from hazardous chemical exposure. No noncarcinogenic health effects are predicted. The maximum HI for the maximally exposed noninvolved worker would be 6×10^{-4}, and no health effect is predicted unless the HI is 1 or higher.

The aggregate total to noninvolved workers at the WIPP site indicated in Table 5-31 shows that no LCFs (5×10^{-4} LCFs) or cancer incidence (1×10^{-4} cancers) would be expected during the entire disposal operations period under Action Alternative 1.

5.2.9.3 Involved Workers

Impacts to involved workers who would handle waste during treatment, lag storage, and WIPP disposal operations under Action Alternative 1 are presented in this section. Results are presented in Table 5-32. The methods used to estimate impacts from waste treatment and WIPP disposal operations are described at the beginning of Section 5.1.9 and in Section 5.1.9.3. Additional information is presented in Appendix F. In actuality, all worker exposures to radiation and hazardous chemicals would be controlled to ALARA levels. Administrative controls such as worker and area monitoring, rotation of workers to reduce exposures, and standard operating procedures would be used to limit exposures.

Waste Treatment

Radiological impacts to the involved worker population from waste treatment would be greater than nonradiological impacts. A maximum of 1.5 radiation-related LCFs could occur in the worker population, while no cancer incidence (3×10^{-5} cancers) would be expected from hazardous chemical exposure. No noncarcinogenic health effects are predicted. The maximum exposure index for a waste treatment worker would be 3×10^{-4}, and no health effect is predicted unless the HI is 1 or higher. Additional information is presented in Appendix F.

Table 5-32
Lifetime Human Health Impacts to Involved Workers from Waste Treatment, Lag Storage, and WIPP Disposal Operations for Action Alternative 1 [a]

Category	Waste Treatment Impacts		Lag Storage Impacts		WIPP Disposal Operations Impacts	
	Radiological (LCF)	Hazardous Chemical (Cancer Incidence)	Radiological (LCF)	Hazardous Chemical (Cancer Incidence)	Radiological (LCF)	Hazardous Chemical (Cancer Incidence)
Population					(36 workers)	(36 workers)
Basic Inventory						
CH-TRU Waste	0.7	8E-6	0.5	0.02	0.3	0.01
RH-TRU Waste	0.02	7E-6	≤0.5	≤0.02	≤0.3	1E-3
Total Waste	0.8	2E-5	≤1	≤0.04	≤0.6	0.01
Total Inventory						
CH-TRU Waste	1.5	2E-5	0.5	0.02	0.5	0.03
RH-TRU Waste	0.03	1E-5	≤0.5	≤0.02	≤0.5	1E-3
Total Waste	1.5	3E-5	≤1	≤0.04	≤1	0.03
Aggregate Total	1.5	3E-5	≤1	≤0.1	≤1	0.04

[a] The involved worker populations considered for treatment impacts and operations impacts are different.

Lag Storage

Radiological impacts to the involved worker population from lag storage would be less than or equal to 1 LCF, and hazardous chemical impacts would be less than 0.04 cancers. No noncarcinogenic health effects would occur. Involved worker lag storage impacts would be larger from CH-TRU waste storage operations than from RH-TRU waste storage operations because of remote RH-TRU waste handling and greater administrative controls for RH-TRU waste. Therefore, no specific RH-TRU waste lag storage impact estimates were made. Impacts were assumed to be less than or equal to those for CH-TRU waste.

The impacts from CH-TRU waste would be from the external radiation dose received during waste container handling. Potential radiological impacts from inhalation of radioactive gases released from waste containers would be negligible. Involved worker impacts from lag storage were calculated by assuming waste handlers would spend 2 hours every workday at 1 meter (3.3 feet) from the CH-TRU waste containers. The workers were assumed to be exposed over a 35-year career. Container dose rates were decay-corrected over the 35 years, and all sites were assumed to monitor 20 percent of the Total Inventory annually.

The aggregate total indicated in Table 5-32 refers to the impacts to the involved worker population at the lag storage sites over the entire operational period under Action Alternative 1. Lag storage impact estimates conservatively assume that the lag storage period is equivalent to the disposal operations period, which is estimated to be 42 years for CH-TRU waste and 160 years for RH-TRU waste. Less than 1 LCF and no cancer incidence (less than 0.1 cancers) would be expected over the several generations of involved workers that would be exposed externally or via inhalation of hazardous chemicals from lag storage operations. The radiological impact estimates reflect the aggregate impacts analyses presented in detail in Appendix F. The hazardous chemical impacts were estimated in the same manner as the public and noninvolved worker estimates.

WIPP Disposal Operations

Workers would be exposed under the same circumstances as described for the Proposed Action in Section 5.1.9.3. Radiological impacts to the involved worker population from disposal operations

at WIPP would be less than 1 LCF. WIPP involved worker radiological impact estimates were made assuming each involved worker handled the CH-TRU waste for 400 hours per year. The operational period was determined by assuming that 2.5 years of disposal operations were required to fill each panel. Impacts to involved workers from RH-TRU waste handling were assumed to be the same or less than those from CH-TRU waste handling. This assumption is conservative because RH-TRU waste is typically handled using remote-handling equipment, workers are usually protected by radiation shielding, and stricter administrative procedures are used. The impact from handling RH-TRU waste, therefore, would probably be less than the impact from handling CH-TRU waste.

Hazardous chemical impacts to the involved worker population would be 0.03 cancers, and no noncarcinogenic health effects would occur. Involved worker exposures to VOCs were evaluated in the Waste Handling Building and underground, as was done for the Proposed Action. The potential carcinogenic impacts would be greatest for the individual underground worker. Noncarcinogenic health effects were also estimated. The same methods and assumptions were used as for the Proposed Action (Section 5.1.9.3). Workers were assumed to be exposed for 35 years. The results were the same as those presented for the Proposed Action.

The aggregate total indicated in Table 5-32 refers to the impacts to the involved worker population at WIPP over the entire disposal operations period under Action Alternative 1. Less than 1 LCF and 0.04 cancers are expected from external radiation or hazardous chemical exposures, respectively, over the several generations of involved workers at WIPP. Radiological impacts over the entire operational period would be approximately twice the number of impacts estimated for the individual during the first 35 years of CH-TRU waste disposal operations at WIPP. Radiological decay would reduce the radiological impacts to each generation of WIPP workers. Hazardous chemical impacts were conservatively estimated by assuming continuous exposure to the same releases over the entire disposal operations period.

5.2.10 Facility Accidents

Impacts under Action Alternative 1 would be the same as those for the Proposed Action for treatment and WIPP disposal accidents. However, there would be lag storage of CH-TRU and RH-TRU waste under Action Alternative 1; therefore, impacts resulting from storage accidents are discussed for the six sites under evaluation (Hanford, LANL, INEEL, SRS, RFETS, and ORNL). Impacts of storage accidents were evaluated for storage at these six sites because they would store about 99 percent of the CH-TRU and RH-TRU waste under Action Alternative 1.

5.2.10.1 Waste Treatment Accidents

The impacts from waste treatment accidents under Action Alternative 1 would be the same as those under the Proposed Action (see Section 5.1.10.1).

5.2.10.2 Waste Storage Accidents

Three potential waste storage accidents were evaluated for Action Alternative 1 (see Table 5-33). The results are presented only for accidents involving CH-TRU waste because they would be greater than the results for similar accidents involving RH-TRU waste. (The impacts from failure of RH-TRU storage facilities as a result of an earthquake are presented in Appendix G). Lower transuranic radionuclide activity in RH-TRU waste (lower PE-Ci levels, see Table G-23 and

Table G-24), lower RH-TRU waste volume, more robust waste containers for RH-TRU waste, and presumably more robust construction of RH-TRU waste storage facilities (thick concrete walls for external radiation shielding) would all combine to limit potential impacts from RH-TRU waste accidents. Waste would be consolidated at 10 sites for lag storage under Action Alternative 1.

Table 5-33
Storage Accident Scenarios Evaluated for Action Alternative 1

Accident Scenarios	Annual Occurrence Frequency	Description
Drum Puncture, Drop, and Lid Failure (Accident Scenario S1)	1E-2 to 1E-4	A forklift strikes and punctures a drum on a lower level of a stack in the storage facility. The stack is destabilized and two drums fall to the ground and lose their lids upon impact.
Drum Fire (Accident Scenario S2)	1E-4 to 1E-6 (<8 PE-Ci) <1E-6 (>8 PE-Ci)	A fire spontaneously erupts in a waste drum.
Earthquake (Accident Scenario S3)	1E-5 or less	A beyond-design-basis earthquake (or other natural event) occurs, causing the storage building to collapse.

Storage accidents analyzed include a high-frequency/low-consequence operational accident which is expected to be applicable under any facility design, a low-frequency/high-consequence operational accident, and a beyond-design-basis natural disaster accident. For Accident Scenarios S1 and S2, CH-TRU waste involved in the accidents was assumed to have the highest levels of radionuclides (80 PE-Ci per drum) permitted by the planning-basis WAC, conservative concentrations of VOCs (based on CH-TRU waste sampling and planning-basis WAC limits) and conservative concentrations of heavy metals. Accident Scenario S3 involves a large number of waste containers; therefore, site-specific drum PE-Ci values and average hazardous chemical concentrations were used in the analyses. Additional details on the accident analyses are presented in Appendix G.

Estimated radiological impacts are presented as the number of LCFs in the exposed population and as the probability of an LCF occurring in MEIs. Carcinogenic and noncarcinogenic impacts from hazardous chemicals, both VOCs and heavy metals, were estimated. Carcinogenic impacts are presented as the number of cancers in the exposed population and the probability of cancer for MEIs. Noncarcinogenic impacts from exposure to VOCs and heavy metals were estimated by two different methods for the drum puncture and drum fire scenarios (Accident Scenarios S1 and S2, respectively): IDLH-equivalent ratios and ERPG ratios. Only IDLH-equivalent ratios were calculated for the earthquake scenario (Accident Scenario S3). The potential noncarcinogenic impacts identified by ERPG ratios would be of minor importance during such a catastrophic event and its consequent site-operations upheaval.

In general, potential radiological impacts would be higher than hazardous chemical impacts, which are very small for most accident cases. Estimated results for members of the public, the maximally exposed noninvolved worker, and the maximally exposed involved worker are presented below and in Table 5-34.

Table 5-34
Radiological Consequences from Storage Accidents for Action Alternative 1 [a]

Accident Scenarios	Population (number of LCFs)	MEI (probability of an LCF)	Maximally Exposed Noninvolved Worker (probability of an LCF)
Drum Puncture and Lid Failure (Accident Scenario S1)	Maximum: 5E-4 (RFETS)	Maximum: 3E-7 (ORNL)	Maximum: 4E-7 (Hanford)
Drum Fire (Accident Scenario S2)	Maximum: 2E-3 (RFETS, ORNL)	Maximum: 1E-6 (ORNL)	Maximum: 2E-6 (Hanford, LANL, ORNL)
Earthquake (Accident Scenario S3-CH)	Hanford: 200 INEEL: 6 LANL: 50 RFETS: 300 ORNL: 6 SRS: 38	Hanford: 0.1 INEEL: 3E-3 LANL: 0.1 RFETS: 0.02 ORNL: 6E-3 SRS: 4E-3	Hanford: 1 INEEL: 0.6 LANL: 0.6 RFETS: 0.6 ORNL: 0.01 SRS: 1

[a] The site with the greatest impact is shown in parentheses.

Note: This table presents estimates of the consequences of accident scenarios and does not reflect the frequency (or probability) of the accident occurring.

Public

Population impacts from storage accidents were estimated for the exposed populations around the six major treatment sites. Potential impacts to the population and MEIs at the six sites vary over a wide range because of different population distributions, distances to the MEIs, and atmospheric dispersion factors among the sites. No LCFs would be expected in the exposed population from drum puncture or drum fire accidents (Accident Scenarios S1 and S2, respectively), but LCFs were estimated to occur from the earthquake accident (Accident Scenario S3) at all sites. The number of LCFs ranged from 6 (at ORNL and INEEL) to 300 (at RFETS). The radiological impacts were estimated to be the highest to the MEI at ORNL for the drum puncture and drum fire accidents (Accident Scenarios S1 and S2). Impacts from the earthquake accident (Accident Scenario S3) were estimated to range from 3×10^{-3} to 0.1 probability of an LCF to the MEI.

Carcinogenic impacts from VOCs would be one to six orders of magnitude greater than impacts from heavy metals for the drum puncture and earthquake scenarios (Accident Scenarios S1 and S3, respectively). Heavy metals account for all carcinogenic impacts from the drum fire accident (Accident Scenario S2) because VOCs would be consumed by the fire. No cancer was estimated to occur in the exposed population from the hazardous chemical releases of any accident. The maximum probability of cancer to an MEI would be 9×10^{-10} for the drum puncture and drum fire scenarios (Accident Scenarios S1 and S2, respectively). The maximum probability of cancer to the MEI would be 9×10^{-7} for the earthquake accident (Accident Scenario S3). No noncarcinogenic impacts would be expected for any of the three accidents evaluated.

Maximally Exposed Noninvolved Worker

The maximally exposed noninvolved worker was assumed to be at the location of greatest impact outside of the waste storage facility. The impacts to the noninvolved worker would vary over a narrow range across the six sites evaluated. The range was narrow because similar conditions were assumed to exist at the six sites.

Radiological impacts to the maximally exposed noninvolved worker would result in a 4×10^{-7} probability of an LCF (at Hanford) from events of the drum puncture scenario (Accident Scenario S1), a 2×10^{-6} probability of an LCF (at Hanford, LANL, or ORNL) from the events of the drum fire scenario (Accident Scenario S2), and up to a probability of 1 of an LCF (at Hanford and SRS) from the beyond-design-basis earthquake (Accident Scenario S3).

Hazardous chemical impacts would be relatively minor in comparison to the radiological impacts. The maximum probability of cancer to the maximally exposed noninvolved worker from VOC and heavy metal intakes would be 1×10^{-9} for the drum puncture and drum fire scenarios (Accident Scenarios S1 and S2, respectively). The corresponding impact for the earthquake scenario (Accident Scenario S3) would be a 5×10^{-6} probability of cancer. A Hanford noninvolved worker could experience a minor noncarcinogenic health effect from drum puncture releases (Accident Scenario S1) of 1,1,2,2-tetrachloroethane.

Maximally Exposed Involved Worker

The involved worker would be the individual most seriously impacted by the events of the drum puncture and earthquake scenarios (Accident Scenarios S1 and S3, respectively) because of close proximity to the accidents. Impacts were quantitatively estimated for the drum puncture scenario (Accident Scenario S1). The maximally exposed involved worker could have a 0.06 probability of an LCF as a result of the radionuclide intake from this accident. The analysis assumed the instantaneous radioactive material releases from the three containers, expanding in a uniform hemisphere of 5 meters (16 feet) in radius. The worker was assumed to inhale this air for 1 minute prior to exiting to a fresh air source.

The involved worker could have a 7×10^{-8} probability of contracting cancer from estimated hazardous chemical intakes due to the events of the drum puncture scenario (Accident Scenario S1). Noncarcinogenic impacts could be irreversible but would not be life-threatening under the assumed exposure assumptions. These impacts could result from the potential releases of 1,1,2,2-tetrachloroethane, and methylene chloride. Mild impacts might result from lead and mercury releases.

Impacts from the drum fire scenario (Accident Scenario S2) would be serious if the worker happened to be adjacent to the drum when the fire began. However, a worker's actions are not required to initiate the accident; therefore the probability of exposure of a worker adjacent to the fire is small. The smoke being released from the drum would alert workers to the incident, and it can be reasonably assumed that workers would avoid exposure to the smoke.

Catastrophic destruction of the storage facility during an earthquake or other natural events (Accident Scenario S3) could result in death or serious injury to the maximally exposed involved worker due to a falling ceiling or other debris and radiation doses.

5.2.10.3 WIPP Disposal Accidents

The impacts from accidents during WIPP disposal operations under Action Alternative 1 would be the same as those under the Proposed Action (see Section 5.1.10.3).

5.2.11 Industrial Safety

A total of four fatalities from industrial accidents would occur under Action Alternative 1 during waste treatment at all treatment sites. This result was determined by adjusting the physical-hazard fatality estimate of the WM PEIS.

Under Action Alternative 1, the WIPP operational activities would be essentially the same as those conducted under the Proposed Action but would last approximately 160 years rather than 35 years. Decommissioning activities would be the same as under the Proposed Action. Estimated industrial safety impacts to workers under Action Alternative 1 are presented in Table 5-35. Oversight and inspections by the MSHA and adherence to OSHA regulations would probably reduce actual occurrences below these estimated values.

Table 5-35
Industrial Safety Impacts from WIPP
Operations and Decommissioning for Action Alternative 1

Years	Injuries/Illnesses			Fatalities		
	Construction	Operations	Total	Construction	Operations	Total
Operations 1998-2158	99	5,600	5,699	0.2	5.6	5.8
Decommissioning 2159-2168	187	96	283	0.3	0.1	0.4
Total	286	5,696	5,982	0.5	5.7	6.2

5.2.12 Long-Term Performance

This section presents the potential impacts associated with the long-term performance of the WIPP repository for Action Alternative 1 over the 10,000-year period after the site is closed. These impacts were estimated based on computer simulations that predicted radionuclide and heavy metal releases from TRU waste in the repository under undisturbed and disturbed conditions. Analyses were conducted using the same methods as for the Proposed Action and other action alternatives; additional information is presented in Appendix H. The waste volume emplaced would be 281,000 cubic meters (9.9 million cubic feet) of CH-TRU waste and 55,000 cubic meters (1.9 million cubic feet) of RH-TRU waste. The repository size was increased from the 10 panels of the Proposed Action to 68 panels to accommodate the increased waste volume. The radionuclide inventory was increased to 7.3×10^6 Ci in CH-TRU waste and 5.1×10^6 Ci in RH-TRU waste. There were similar increases in heavy metal inventories. Detailed information on the radionuclide and heavy metal inventories is provided in Appendix A.

The four cases below were analyzed for Action Alternative 1. The cases are the same as the Proposed Action and other action alternatives but include alternative-specific differences, such as repository size and radionuclide and heavy metal inventories.

- Case 6 considered undisturbed repository conditions. Median parameter values were used for input variables where probability distributions have been defined.

- Case 7 considered disturbed conditions resulting from a borehole assumed to pass through the repository and intercept a pressurized brine reservoir in the Castile Formation. Median parameters values were used for input variables where probability distributions have been defined.

- Case 8 was the same as Case 6 but used 75th percentile parameter values for input variables where probability distributions have been defined.

- Case 9 was the same as Case 7 but used 75th percentile parameter values for input variables where probability distributions have been defined.

5.2.12.1 Impacts of Undisturbed Conditions

Radionuclide and heavy metal (predominantly lead) migration for undisturbed conditions at 10,000 years after closure for Case 8 (75th percentile parameter values) is presented in Figure 5-3. Case 8 resulted in slightly more extensive migration than Case 6 (median parameter values). Figure 5-3 shows the locations in the modeled region where the concentration of total radionuclide activity in the brine, summed over 30 radionuclides, is equal to 1 pCi per liter (1×10^{-9} Ci per cubic meter). A total heavy metal concentration of one part per billion (1×10^{-3} milligrams per cubic meter) showed approximately the same extent of migration from the repository as the one pCi per liter level of total radionuclide activity concentration.

Approximately the same vertical and lateral migration of radionuclides and heavy metals would occur for Action Alternative 1 as for the Proposed Action. Total radionuclide concentrations of one pCi per liter would extend about 20 meters (65 feet) below the repository, 40 meters (130 feet) above the repository, and about 1,900 meters (6,200 feet) laterally.

Analysis of undisturbed repository conditions (Cases 6 and 8) during the first 10,000 years showed that no radionuclides or heavy metals would be released to the Culebra Dolomite. No total radionuclide activity concentrations greater than 1 pCi per liter or heavy metal concentrations greater than 1 part per billion would be found beyond the 5-kilometer (3-mile) subsurface lateral boundary. There would be no release to the accessible environment and therefore no human health impact. Additional information is provided in Appendix H.

5.2.12.2 Impacts of Disturbed Conditions

This section presents the impacts of two exposure scenarios evaluated for disturbed conditions of Action Alternative 1.

Surface Release Caused by Drilling into the Repository

The human health impacts of drilling into the repository (Case 7 and Case 9) were evaluated for a drilling crew member and a well-site geologist. These individuals were assumed to be exposed to waste material brought to the land surface by drilling, as described in Section 5.1.12.2 and Appendix H. Under Action Alternative 1, 17 repository panels would hold both CH-TRU and RH-TRU waste, and 51 waste panels would hold only RH-TRU waste, so a drilling event could contact CH-TRU, RH-TRU, or both CH-TRU and RH-TRU waste.

The estimated radionuclide releases to the ground surface for Case 7 (median parameter values) would be 2.6, 0.1, and 2.7 Ci, respectively, from CH-TRU waste, RH-TRU waste, and both

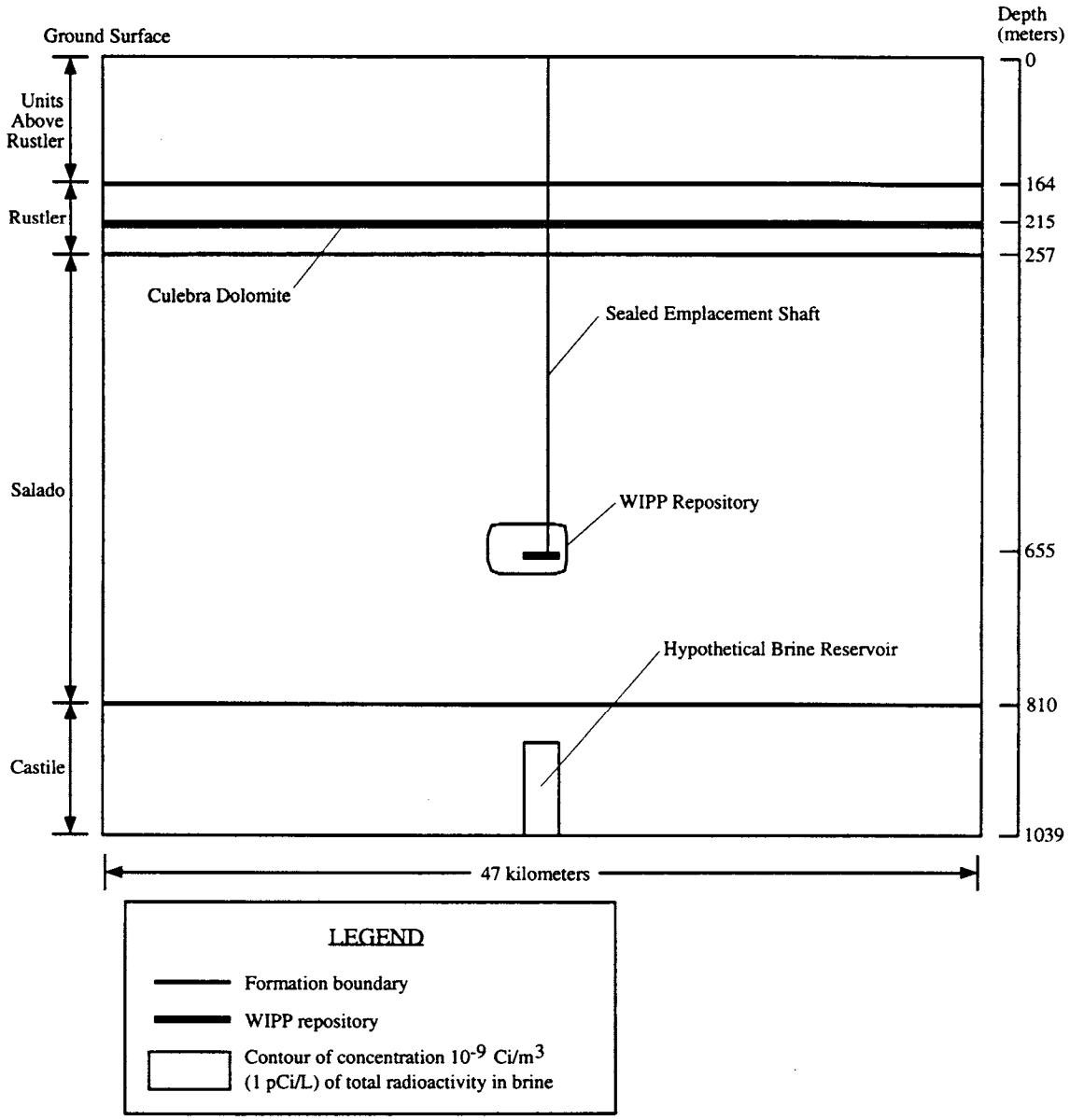


Figure 5-3
Extent of Radionuclide Migration at 10,000 Years with Undisturbed Conditions Using 75th Percentile Parameter Values (Case 8) for Action Alternative 1

CH-TRU and RH-TRU waste. For Case 9 (75th percentile parameter values), the releases would be 3.5 Ci from CH-TRU waste, 0.15 Ci from RH-TRU waste, and 3.6 Ci from CH-TRU and RH-TRU waste. The releases would consist mainly of Pu-238, Pu-239, and Am-241 for all these events. Heavy metal releases from these drilling intrusions would be 6, 22, and 23 kilograms (13, 49, and 50 pounds), respectively, from CH-TRU waste, RH-TRU waste, and both CH-TRU and RH-TRU waste for Case 7 (median parameter values). For Case 9 (75th percentile parameter values), the releases would be 8 kilograms (18 pounds) from CH-TRU waste, 30 kilograms (65 pounds) from RH-TRU waste, and 31 kilograms (67 pounds) from both CH-TRU and RH-TRU waste. Additional information is provided in Appendix H.

The radiological impacts to a drilling crew member for Case 7 (median parameter values) would be a 2×10^{-4}, 7×10^{-6}, and 2×10^{-4} probability of an LCF, respectively, from drilling intrusions of CH-TRU waste, RH-TRU waste, and both CH-TRU and RH-TRU waste. For Case 9 (75th percentile parameter values), the impacts would be higher with a 4×10^{-4}, 1×10^{-5}, and 4×10^{-4} probability of an LCF for the same respective waste type intrusions. Most of the impact would be due to the inadvertent ingestion of drill cuttings (ranging from 83 percent to about 100 percent), with less impact from external radiation dose. Americium-241 would be the major dose contributor. Ingestion of heavy metals for this scenario would result in a 1.7×10^{-8}, 1.0×10^{-9}, and 1.8×10^{-8} probability of cancer incidence, respectively. There would be no noncarcinogenic impacts expected from the ingestion of the metals because all hazard indices would be much less than one. Impacts of exposure to VOCs were not analyzed (see Appendix H) but were expected to be bounded by impacts of VOC exposure under WIPP disposal accidents (see Appendix G). There would be a 3×10^{-7} probability of a cancer incidence. Some short-term toxicological effects from inhalation of VOCs could occur under these assumptions (see Appendix G).

Radiological impacts to the well-site geologist from external radiation exposure for Case 7 (median parameter values) would result in a 2×10^{-9} probability of an LCF from CH-TRU waste and a 2×10^{-9} probability of an LCF from RH-TRU waste. For Case 9 (75th percentile parameter values), the radiological impacts would be a 3×10^{-9} probability of an LCF from CH-TRU waste and a 5×10^{-9} probability of an LCF from RH-TRU waste. Am-241 and U-234 were major external dose contributors in CH-TRU and RH-TRU waste for Case 7 and in CH-TRU waste for Case 9, while Sr-90 and Cs-137 were the major external dose contributors in RH-TRU waste for Case 9.

Drilling through the Repository into a Pressurized Brine Reservoir

Impacts of drilling through the repository into a pressurized brine reservoir were analyzed as described in Section 5.1.12.2 and in Appendix H, using information specific to Action Alternative 1 where appropriate. Analysis of radionuclide and heavy metal migration for this scenario at 10,000 years after closure for Case 7 (median parameters values) showed there would be no radionuclide or heavy metal releases into the Culebra Dolomite or the accessible environment.

The extent of radionuclide (predominantly Pu-238, Pu-239, and Am-241) migration for disturbed conditions at 10,000 years after closure for Case 9 (75th percentile parameters values) is presented schematically in Figure 5-4. Total radionuclide activity concentrations of one pCi per liter are shown. Simulations showed radionuclides migrated upward and downward into the borehole and penetrated into rocks directly in contact with the borehole for a limited distance. For Case 9 only, migration extends upward into the Culebra Dolomite at 10,000 years. Migration also extends downward in the borehole (for both Cases 7 and 9) to the Castile Formation and into the brine

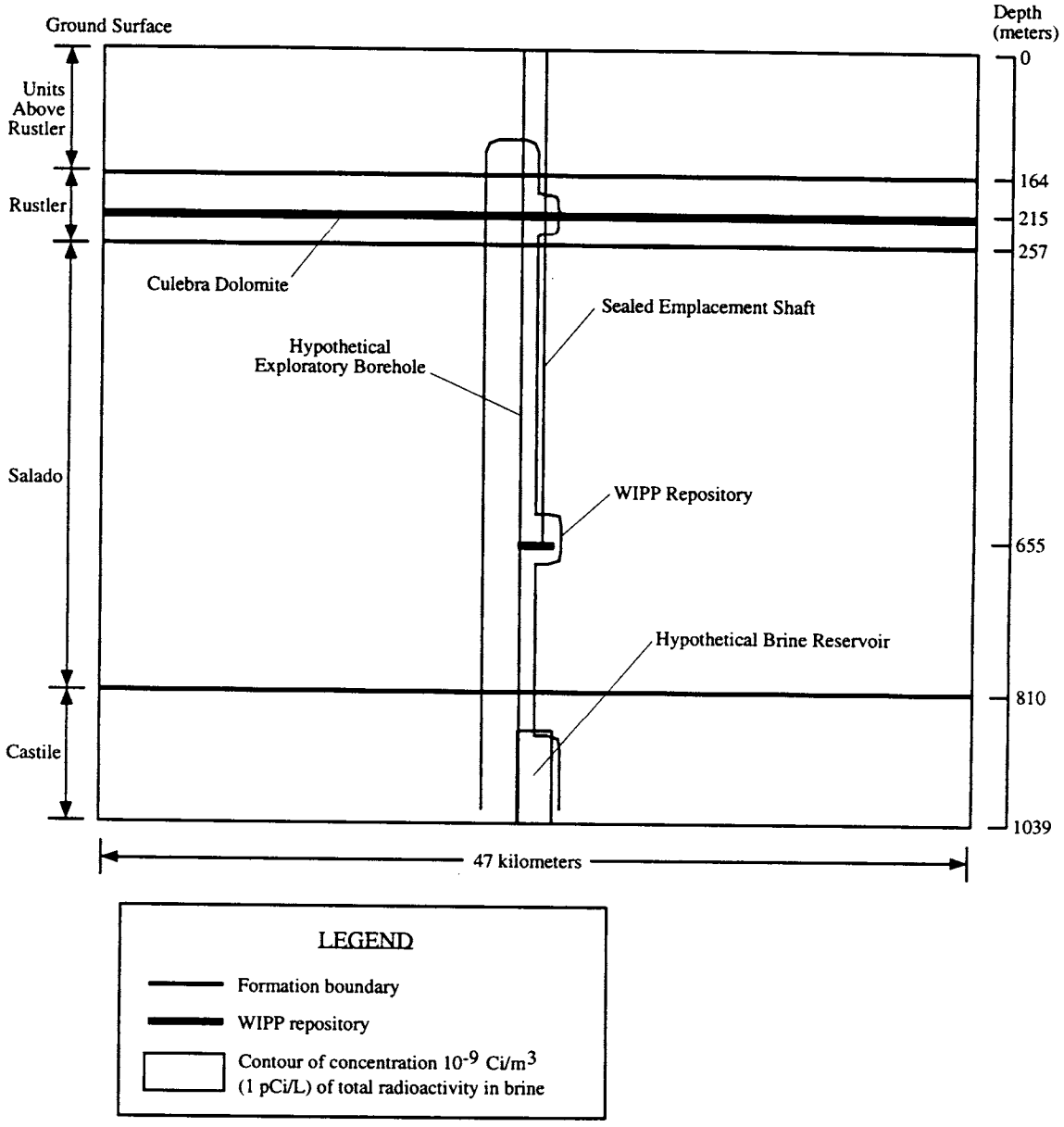


Figure 5-4
Extent of Radionuclide Migration at 10,000 Years with Disturbed Conditions Using 75th Percentile Parameter Values (Case 9) for Action Alternative 1

reservoir. This would occur after the initial pressure in the pressurized brine pocket dissipates and equilibrates with pressures in the repository and overlying units penetrated by the borehole. Total heavy metal concentration of one part per billion (1×10^{-3} milligrams per cubic meter) showed approximately the same extent of migration from the repository as the one pCi per liter level of total radionuclide activity concentration. Predicted brine pressures and additional modeling information is provided in Appendix H.

Impacts of radionuclide and heavy metal migration to the accessible environment were evaluated for Case 9 (75th percentile parameter values) since a release of contaminants into the Culebra Dolomite was indicated for this case only. The exposure scenario was the same as that evaluated for the Proposed Action and other action alternatives, with an individual consuming beef from cattle using the water from a stock well 3 kilometers (2 miles) from the point of intrusion. Results are presented only for partial mining conditions since calculated impacts for full mining conditions were significantly lower (see Section H.8.2). Radiological impacts would be negligible, with a 2×10^{-27} probability of an LCF. The dominant dose contributor was Pu-239. Ingestion of heavy metals from consumption of contaminated beef was also found to result in negligible impacts, with a probability of cancer incidence of 3×10^{-27}. No noncarcinogenic impacts would be expected. Additional information is presented in Appendix H.

5.2.13 Reducing WIPP Operations for Action Alternative 1

As noted in Chapter 3, stakeholders requested a discussion in greater detail of the changes to impacts should the Department reduce the period of operations for WIPP under Action Alternative 1. The period of operations is 160 years, but it could be reduced to 60 years by constructing an additional waste handling building for RH-TRU waste, constructing four new shafts, and tripling the number of excavation and emplacement crews. Additional costs would total $80 million in capital costs and $165 million in annual operating costs.

No additional impacts would be expected at treatment facilities because the facilities and their periods of operation would be identical to those discussed earlier.

The time to ship to WIPP from the treatment facilities would decrease from 160 years to 53 years. The aggregate nonradiological impacts would be the same as those described earlier, except that they would occur within the shorter time period. The accident-free radiological impacts to occupational and nonoccupational populations were reported as aggregate impacts over the entire shipping campaign. Therefore, no increase in impacts would be noted. However, because the MEIs would be exposed to more shipments, the estimated exposure to MEIs would triple. All accident impacts would be identical to those described earlier.

Because the size of the WIPP underground facility would remain the same and because the new facility would be constructed within the footprint of the repository, land use, biological resource, and cultural resource impacts would be similar to those described earlier in this section. Construction of the new waste handling building would increase the air quality impacts slightly for the period of construction. Other air quality impacts would be negligible. Noise impacts would triple because the rate of shipments through Carlsbad would triple. Water quality and infrastructure impacts may be impacted by the new facilities and additional work crews.

Human health impacts would decrease for lag storage. The impacts to the public, noninvolved workers, and involved workers over the entire operations period would remain the same, but be

compressed into about a third of the time. Impacts to the MEIs would triple because triple the waste would be emplaced during a lifetime. Industrial safety impacts would decrease by approximately 50 percent, considering the reduced operation times, construction of new facilities, and the increased number of workers. There would be no change in long-term performance assessment results.

The greatest change in Action Alternative 1 results would be in life-cycle costs, which would drop from $50.95 billion in 1994 dollars ($16.32 billion discounted) to $35.80 billion ($13.24 billion discounted) should only trucks be used. Life-cycle costs should regular rail transportation be used would decrease from $47.68 billion ($15.80 billion discounted) to $32.53 billion ($12.03 billion discounted), and life-cycle costs should dedicated rail transportation be used would decrease from $57.36 billion ($17.33 billion discounted) to $42.21 billion ($15.62 billion discounted).

5.3 IMPACTS OF ACTION ALTERNATIVE 2

This section describes the environmental impacts associated with the implementation of the subalternatives of Action Alternative 2. Under each subalternative, WIPP would accept the Basic Inventory and the Additional Inventory including PCB-commingled TRU waste. All TRU waste would be thermally treated to meet Land Disposal Restrictions (LDR). SEIS-II analyzed three different consolidation and treatment subalternatives, Action Alternatives 2A, 2B and 2C. Action Alternative 2C includes treatment of all CH-TRU waste at WIPP.[1] Each subalternative is described in Section 3.2.3.

The total consolidated, pretreatment volume of waste to be treated under this alternative would be 313,000 cubic meters (11 million cubic feet) (see Tables 3-4 through 3-9). The type, size, and number of treatment facilities needed under this alternative would be comparable to those assessed in the thermal treatment alternatives of the WM PEIS. Treatment under each subalternative would continue for 35 years. The waste would be stored at the treatment facilities until disposal (this storage is called lag storage). The WIPP operational time frame under this alternative would extend to the year 2148 (150 years).

5.3.1 Land Use Management

Land use impacts at the treatment sites for each of the Action Alternative 2 subalternatives would be similar to those under the Proposed Action discussed in Section 5.1.1. Additional waste would be treated under this alternative, but the treatment time period would be extended to 35 years. Though the SEIS-II Action Alternative 2 subalternatives propose treating TRU waste at various DOE locations, in no case would the treatment facilities require more than 1 percent of the available land at those DOE locations. The Department would have a great deal of flexibility when determining the locations of such facilities (DOE 1997). The Department would be able to minimize impacts to on-site land use and would be able to avoid conflicts with off-site land use plans. It also would be able to avoid sensitive or inappropriate land areas (including wetlands, flood plains, cultural resource areas, and the habitats of endangered and threatened species) (DOE 1997). Before treatment facilities would be constructed, further NEPA review would be undertaken at a site-wide or project-specific level.

[1] If the Department decides, based on the WM PEIS analyses, to centralize treatment at WIPP, the Department would prepare further project-specific NEPA review for any proposed treatment facility. Such review would be tiered from SEIS-II.

Land use impacts during disposal operations at WIPP under Action Alternatives 2A, 2B, and 2C would be similar to those under the Proposed Action, discussed in Section 5.1.1. A difference from the Proposed Action would occur during decommissioning and closure, when approximately 395 hectares (976 acres) would be affected due to an increased underground waste disposal area. Like the Proposed Action, the rest of the Land Withdrawal Area would be available to the public for nonintrusive surface activities following decommissioning and closure.

5.3.2 Air Quality

For Action Alternative 2A, the levels of criteria pollutants exceeding 10 percent of the applicable annual regulatory standard during operation of treatment facilities would be those for CO at RFETS (24 percent) and PM_{10} at INEEL (10 percent). For Action Alternative 2B, the levels of criteria pollutants exceeding 10 percent would be PM_{10} at INEEL (10 percent). For Action Alternative 2C, the levels of criteria pollutants exceeding 10 percent would be PM_{10} (25 percent) and SO_2 (12 percent) at WIPP (DOE 1997) (see Appendix C for additional detail). Minor increases in PM_{10} levels may occur during construction.

RFETS, LLNL, NTS, and ANL-E are in nonattainment areas for some of the pollutants. In those areas where air pollution standards are not met (nonattainment areas), activities that introduce new sources of emissions are regulated under the General Conformity Rule. In areas where air pollution standards are met (attainment areas), regulations for the PSD of ambient air quality apply. In both cases, a permit is required for sources that will result in emissions equal to or greater than the limits set by pertinent regulations.

Of hazardous or toxic air pollutant releases, only radionuclide releases would exceed 10 percent of the applicable regulatory standard. For Action Alternative 2A, treatment-related releases could reach 134 percentof the regulatory standard at LANL. For Action Alternative 2B, treatment-related releases could reach 10 percent of the regulatory standard at INEEL. For Action Alternative 2C, releases could reach 137 percent of the regulatory standard at WIPP. Postulated waste treatment-related releases above the regulatory standard would require mitigation measures, such as HEPA filtration, to ensure they remained below the allowable limit.

The potential air quality impacts from the operation of WIPP for disposal under Action Alternatives 2A, 2B, and 2C would be the same as those anticipated under the Proposed Action. Although the increased waste disposal volume at WIPP would increase the duration of disposal activities, there would be no substantial difference in the rate of pollutant emissions on either an annual or a short-term basis.

Potential air quality impacts due to the decommissioning of WIPP under Action Alternative 2 would be similar to those under the Proposed Action. Construction of the berm and permanent markers and other decommissioning activities would last longer than under the Proposed Action and other alternatives, but would probably produce negligible increases in annual pollutant emissions compared to the other alternatives.

5.3.3 Biological Resources

The biological impacts at the treatment sites (including WIPP) for Action Alternatives 2A, 2B, and 2C would be the same as those for the Proposed Action. Though additional waste would be treated using a different treatment method, the size, type, and number of the treatment facilities would be

comparable to those assessed in the WM PEIS, which determined that construction and operation of the treatment facilities should not affect populations of nonsensitive plant and animal species. Also, terrestrial wildlife species probably would not be affected by airborne emissions nor by spills into aquatic environments due to traffic accidents (DOE 1997). Threatened and endangered species may be present at all of the proposed treatment sites; however, impacts to these species would depend on the actual location of the facility at a particular site. Site selection would be conducted following appropriate Endangered Species Act consultation and site-wide or project-level NEPA review during which such impacts would be assessed and mitigated, if necessary. The critical habitats of species listed by the state and federal governments as endangered, threatened or candidates would be avoided.

Federally listed, threatened and endangered, and state-listed species occur in Eddy County and potentially at the WIPP, although DOE has not observed threatened, endangered, or proposed species or critical habitats at the WIPP site during surveys conducted for recent biennial environmental compliance reports. DOE recently completed a site-specific biological survey yet to be published, during which no endangered, threatened, or state-listed species were identified.

At WIPP, potential impacts on biological resources for disposal operations would be similar to those under the Proposed Action, described in Section 5.1.3. The increased underground waste disposal area, though, would lead to greater impacts during closure and post-closure activities. Approximately 395 hectares (976 acres) of aboveground area would be affected by decommissioning, salt pile reclamation, and closure construction of berms and permanent markers. These activities would disturb avian and small mammal habitat within and near the area. These disturbed areas would be attractive as habitat after natural vegetation recolonizes.

5.3.4 Cultural Resources

The impacts to cultural resources at the treatment sites under Action Alternatives 2A, 2B, and 2C would be the same as those for the Proposed Action. Construction and operation of treatment facilities (including that proposed for WIPP under Action Alternative 2C) could adversely affect cultural resources, but site-level cultural resource surveys would be conducted, and protection measures established, where necessary, when specific facility construction locations are proposed. These surveys would be part of site-wide or project-level NEPA reviews.

Waste shipment and disposal activities at WIPP would not have an impact on archaeological sites; however, some sites could be affected by expansion of the disposal area and closure- and decommissioning-related activities. The land that would be disturbed due to closure and decommissioning under Action Alternatives 2A, 2B, and 2C covers a substantially larger area (395 hectares [976 acres]) than that under the Proposed Action.

Since publication of SEIS-I in 1990, additional cultural resource surveys have been conducted at WIPP. Based on inventory data, and assuming environmental homogeneity and a fairly even distribution of archaeological sites, DOE estimates that the WIPP site may contain about 99 archaeological sites and 153 locations where isolated artifacts may exist. There are no known Native American sacred sites or burials in the Land Withdrawal Area.

Measures for ensuring protection of known archaeological and historic resources, or others that may be inadvertently discovered during ground-disturbing activities, are discussed in the *Waste Isolation Pilot Plant Land Management Plan* (DOE 1996a). DOE will avoid, to the extent

possible, sites found eligible for inclusion in the NRHP. Where avoidance is not possible, mitigation measures will be developed under the Joint Powers Agreement with the State of New Mexico.

5.3.5 Noise

Treatment sites would probably be located in industrial areas along high-volume highway corridors; therefore, ambient noise levels are not likely to increase substantially, although some sensitive receptors may be affected (DOE 1997). Further assessment of these impacts was reserved until actual siting of treatment facilities is proposed in a site-wide or project-specific NEPA document. Under each Action Alternative 2 subalternative, all waste would travel to WIPP, but only a portion of the waste would travel from or to each treatment facility; therefore, the greatest impacts due to transportation noise would be near the WIPP site.

Disposal operations at WIPP would result in noise impacts similar to those discussed for the Proposed Action in Section 5.1.5. Potential noise impacts at WIPP from truck transportation also would be similar to those under the Proposed Action (Section 5.1.5). Estimated rail noise from transportation would be similar to those under Action Alternative 1 (Section 5.2.5).

5.3.6 Water Resources and Infrastructure

The following sections discuss the water resource and infrastructure impacts of the three Action Alternative 2 subalternatives.

Action Alternative 2A

Although no off-site infrastructure impacts would be expected to occur; proposed TRU waste activities may affect on-site activities. The affected infrastructure elements analyzed were on-site transportation and the capacity of on-site water, power, and wastewater systems. For Action Alternative 2A, on-site demand for wastewater at Hanford would exceed 5 percent of current demand (7.8 percent) and at INEEL, an increase in the on-site demand for power of 6.6 percent would occur.

Minor impacts to the on-site transportation infrastructure would be expected under Action Alternative 2A. These impacts would result from an increase in on-site employment of 9 percent at Hanford and INEEL and 7 percent at LANL. Impacts to the off-site transportation infrastructure would not occur because population increases would not exceed 5 percent.

Negligible annual infrastructure impacts would be expected at WIPP under Action Alternative 2A. Existing water supply and sewer capabilities and existing and planned power and roadway resources will be able to accommodate proposed disposal operations.

Action Alternative 2B

For Action Alternative 2B, Hanford would have an increase in on-site demand for wastewater that would exceed 5 percent of current demands (7.8 percent) and INEEL would have an increase in the on-site demand for power by 6.6 percent.

Minor impacts to the on-site transportation infrastructure would be expected under Action Alternative 2B. These impacts would result from an increase in on-site employment of 9 percent at

Hanford and 11 percent at INEEL. Impacts to the off-site transportation infrastructure would not occur because population increases would not exceed 5 percent.

Negligible annual infrastructure impacts at WIPP would be expected under Action Alternative 2B for disposal operations. Existing water supply and sewer capabilities and existing and planned power and roadway resources will be able to accommodate proposed disposal operations.

Action Alternative 2C

The greatest incremental impacts to infrastructure would occur under Action Alternative 2C due to treatment activities at the WIPP site. Expected impacts under Action Alternative 2C include INEEL increasing on-site demand for power by 6.6 percent and WIPP increasing wastewater treatment demand by approximately 80 percent and power by 50 percent. The increase in wastewater treatment demand at WIPP could exceed the current system capacity by approximately 60 percent. The increase in power demand at WIPP would not cause total power demand to exceed 90 percent of current capacity.

Minor impacts to the on-site transportation infrastructure would be expected under Action Alternative 2C. These impacts result from an increase in on-site employment of 6 percent at Hanford and 162 percent at WIPP. Impacts to the off-site transportation infrastructure would not be anticipated because population increases would not exceed 5 percent.

Negligible annual infrastructure impacts would be expected at WIPP under Action Alternative 2C for disposal operations. Existing water supply and sewer capabilities and existing and planned power and roadway resources will be able to accommodate proposed disposal operations.

5.3.7 Socioeconomics

Estimated life-cycle costs and potential socioeconomic impacts for the Action Alternative 2 subalternatives are presented in the following subsections.

5.3.7.1 Life-Cycle Costs

The life-cycle costs of the three Action Alternative 2 subalternatives are presented in the following subsections.

Life-Cycle Costs for Action Alternative 2A

Table 5-36 shows the life-cycle costs under Action Alternative 2A. Waste treatment facility costs reflect construction, O&M, and D&D at the waste treatment sites, which would thermally treat waste to meet the LDRs and package the waste over a period of 35 years. In addition, Hanford, which has the largest volume, would store portions of the treated waste over a period of 150 years because of WIPP emplacement limitations. Life cycle costs include an additional $700 million to account for treatment to planning-basis WAC of waste that would be shipped for thermal treatment. The waste treatment facility life-cycle costs would be $27.69 billion (in 1994 dollars).

Table 5-36
Life-Cycle Costs for Action Alternative 2A (in millions of 1994 dollars) [a]

Cost Information	Basic Inventory			Additional Inventory			Total	Total Discounted
	CH-TRU Waste	RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU Waste	RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU and RH-TRU Waste
Treatment Facilities	11,000	4,500	15,500	11,340	850	12,190	27,690	15,360
Transport by Truck	870	920	1,790	1,100	100	1,200	2,990	510
Transport by Regular Train	290	310	600	370	30	400	1,010	170
Transport by Dedicated Train	2,010	2,100	4,110	2,530	220	2,750	6,860	1,160
Disposal at WIPP	10,000	2,600	12,600	10,500	230	10,730	23,330	3,700
Total Life-Cycle Cost (Truck)	21,870	8,020	29,890	22,940	1,180	24,120	54,010	19,560
Total Life-Cycle Cost (Regular Train)	21,290	7,410	28,700	22,210	1,110	23,320	52,030	19,220
Total Life-Cycle Cost (Dedicated Train)	23,010	9,200	32,210	24,370	1,300	25,670	57,880	20,210

[a] The methods and assumptions used to estimate the various cost components are described in Appendix D. Actual totals may differ due to rounding.

Life-cycle costs also include one of three options for TRU waste transportation between consolidation sites and WIPP: (1) trucks, as explained under the Proposed Action, (2) truck and rail using commercial rail as explained under Action Alternative 1, and (3) truck and rail using dedicated rail, also as explained in Action Alternative 1. Rail routes would be used to the greatest extent practicable. Under these options, transportation costs include the consolidation of waste volumes at the treatment sites and shipment via truck or rail to WIPP for emplacement. The waste transport life-cycle costs would be about $2.99 billion by truck, $1.01 billion by regular rail, and $6.86 billion by dedicated rail.

The WIPP life-cycle costs would be $23.33 billion. The total life-cycle costs of Action Alternative 2A would be $54.01 billion ($19.56 billion when discounted) using truck, $52.03 billion ($19.22 billion when discounted) using regular rail, or $57.88 billion ($20.21 billion when discounted) using dedicated rail transportation.

Life-Cycle Cost for Action Alternative 2B

The life-cycle costs of Action Alternative 2B are presented in Table 5-37. This alternative would involve the same combined CH-TRU and RH-TRU waste volumes considered under Action Alternative 2A. However, the waste management facility costs include waste treatment at fewer TRU waste treatment sites. Again, due to WIPP emplacement limitations, the site with the largest volume (Hanford) would incur additional storage costs over the life of the project. Life-cycle costs include an additional $3.8 billion to account for treatment to planning-basis WAC of waste that would be shipped for thermal treatment. The waste treatment facility life-cycle costs at the treatment sites would be $30.55 billion (in 1994 dollars).

Table 5-37
Life-Cycle Costs for Action Alternative 2B (in millions of 1994 dollars) [a]

Cost Information	Basic Inventory			Additional Inventory			Total	Total Discounted
	CH-TRU Waste	RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU Waste	RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU and RH-TRU Waste
Treatment Facilities	12,150	4,960	17,110	12,500	940	13,440	30,550	16,940
Transport by Truck	960	1,010	1,970	1,220	110	1,330	3,300	560
Transport by Regular Train	330	350	680	420	40	460	1,140	190
Transport by Dedicated Train	2,190	2,290	4,480	2,760	240	3,000	7,480	1,260
Disposal at WIPP	10,000	2,600	12,600	10,500	230	10,730	23,330	3,700
Total Life-Cycle Cost (Truck)	23,110	8,570	31,680	24,220	1,280	25,500	57,180	21,190
Total Life-Cycle Cost (Regular Train)	22,480	7,910	30,390	23,420	1,210	24,630	55,020	20,830
Total Life-Cycle Cost (Dedicated Train)	24,340	9,850	34,190	25,760	1,410	27,170	61,360	21,900

[a] The methods and assumptions used to estimate the various cost components are described in Appendix D. Actual totals may differ due to rounding.

As under Action Alternative 2A, three options for waste transportation between consolidation sites and WIPP were examined: (1) trucks, as in the Proposed Action, (2) truck and rail using commercial rail as in Action Alternative 1, and (3) truck and rail using dedicated rail service, also as in Action Alternative 1. Rail routes would be used to greatest extent practicable. Transportation costs reflect consolidating the waste volumes at the treatment sites, and then shipping the waste to WIPP for emplacement. The life-cycle waste transport costs would be about $3.30 billion by truck, $1.14 billion by regular rail, and $7.48 billion by dedicated rail.

The WIPP life-cycle costs would be $23.33 billion. The total life-cycle costs of Action Alternative 2B would be $57.18 billion ($21.19 billion when discounted) using truck, $55.02 billion ($20.83 billion when discounted) using regular rail, or $61.36 billion ($21.90 billion when discounted) using dedicated rail transportation.

Life-Cycle Costs for Action Alternative 2C

The life-cycle costs for Action Alternative 2C are presented in Table 5-38. The same combined CH-TRU and RH-TRU waste volumes were considered for this subalternative as were considered under the other Action Alternative 2 subalternatives. Life-cycle costs include an additional $18.5 billion to account for treatment of waste to planning-basis WAC so the waste can be shipped for thermal treatment. Waste treatment facility costs include the activities at Hanford and ORNL for RH-TRU waste and WIPP for CH-TRU waste. The largest site (Hanford) would incur additional storage costs over the 150-year period due to WIPP emplacement limitations. The waste treatment facility life-cycle costs would be $28.7 billion (in 1994 dollars).

The RH-TRU waste transportation costs reflect consolidation of the RH-TRU waste volumes at Hanford and ORNL for treatment and shipment to WIPP. The CH-TRU transportation costs reflect consolidation of CH-TRU waste volumes at WIPP. Transportation modes analyzed included truck, regular rail service, and dedicated rail service. The life-cycle waste transportation costs would be about $2.91 billion by truck, $910 million by regular rail, and $6.54 billion by dedicated rail.

Table 5-38
Life-Cycle Costs for Action Alternative 2C (in millions of 1994 dollars) [a]

Cost Information	Basic Inventory			Additional Inventory			Total	Total Discounted
	CH-TRU Waste	RH-TRU Waste	CH-TRU Waste and RH-TRU Waste	CH-TRU Waste	RH-TRU Waste	CH-TRU Waste and RH-TRU Waste	CH-TRU Waste and RH-TRU Waste	CH-TRU Waste and RH-TRU Waste
Treatment Facilities [b]	8,330	9,630	17,960	8,730	2,010	10,740	28,700	15,910
Transport by Truck	1,160	910	2,070	740	100	840	2,910	490
Transport by Regular Train	360	290	650	230	30	260	910	150
Transport by Dedicated Train	2,610	2,050	4,660	1,660	220	1,880	6,540	1,100
Disposal at WIPP	10,000	2,600	12,600	10,500	230	10,730	23,330	3,700
Total Life-Cycle Cost (Truck)	19,490	13,140	32,630	19,970	2,340	22,310	54,940	20,100
Total Life-Cycle Cost (Regular Rail)	18,690	12,520	31,210	19,460	2,270	21,730	52,940	19,760
Total Life-Cycle Cost (Dedicated Rail)	20,940	14,280	35,220	20,890	2,460	23,350	58,570	20,720

[a] The methods and assumptions used to estimate the various cost components are described in Appendix D. Actual totals may differ due to rounding.
[b] All CH-TRU waste treatment occurs at the WIPP site under this subalternative.

The WIPP life-cycle disposal costs would be $23.33 billion. The total life-cycle costs of Action Alternative 2C would be $54.94 billion ($20.10 billion when discounted) using truck, $52.94 billion ($19.76 billion when discounted) using regular rail or $58.57 billion ($20.72 billion when discounted) using dedicated rail transportation.

5.3.7.2 Economic Impacts

TRU waste treatment activities would support direct, indirect, and induced jobs. Action Alternative 2A would support approximately 28,000 jobs in the ROIs of the six treatment sites (Hanford, INEEL, LANL, ORNL, RFETS, and SRS). Action Alternative 2B would support approximately 28,500 jobs in the ROIs of the four treatment sites (Hanford, INEEL, ORNL, and SRS). Action Alternative 2C would support approximately 7,200 jobs in the ROIs of the three treatment sites (Hanford, ORNL, and WIPP).

Estimates of the impacts of Action Alternatives 2A, 2B, and 2C on employment, income, and the production of goods and services within the WIPP ROI are presented in Table 5-39. For Action Alternatives 2A and 2B, these impacts were estimated using an average annual budget of $180 million per year (in 1994 dollars) over a 150-year period of waste disposal operations. Over this period, the WIPP facility would remain a stable federal employer in the ROI economy, providing direct employment for 1,095 site personnel annually. Indirectly, the operation of WIPP as a waste emplacement facility (from 1998 through 2148) would annually support 2,443 indirect and induced jobs in the ROI work force. The total WIPP-induced employment within the ROI is estimated to be 3,538 per year reflecting the sum of these direct and indirect employment levels.

Table 5-39
Economic Impacts within the WIPP ROI for Action Alternatives 2A, 2B, and 2C

Economic Effects	Total Output of Goods and Services (in millions of 1994 dollars)	Total Employment and Part-Time Jobs)	Total Labor Income (in millions of 1994 dollars)	Carlsbad Output of Goods and Services (in millions of 1994 dollars)	Carlsbad Employment (Full- and Part-Time Jobs)	Carlsbad Labor Income (in millions of 1994 dollars)
Action Alternatives 2A and 2B						
Direct – Annual	113	1,095	52	95	979	46
Indirect & Induced – Annual	204	2,443	75	172	2,185	67
Total – Annual	317	3,538	126	267	3,164	113
Total - Operations (150 years)	47,550	530,700	18,900	40,050	474,600	16,950
Action Alternative 2C						
Direct – Annual	220	2128	100	185	1903	90
Indirect & Induced – Annual	396	4748	145	334	4246	130
Total – Annual	616	6876	245	519	6148	220
Total - Operations (150 years)	92,400	1,031,400[a]	36,750	77,850	922,200 [a]	33,000

[a] Job-years (number of annual jobs supported multiplied by the number of years in the project).

Action Alternatives 2A and 2B would not be expected to result in any socioeconomic impacts in the WIPP ROI beyond those associated with WIPP disposal operations, such as additional government-provided goods or services (schools, police, fire protection, and health protection), or major capital investments in public infrastructure within the ROI. Action Alternatives 2A and 2B would not be expected to impact the local real estate market, nor result in major changes in WIPP ROI work force population.

Under Action Alternative 2C, however, the economic impacts were estimated using an average annual budget of $350 million per year over a 150-year period. Because of the relatively larger scope of operations, Action Alternative 2C would have relatively larger economic impacts in the WIPP ROI, and Carlsbad, in particular. The combination of treatment and emplacement operations is estimated to provide direct employment for 2,128 site personnel annually. The combined operations would annually support 4,748 indirect and induced jobs in the ROI work force. The total WIPP-related employment impact within the ROI is estimated to be 6,876 per year, reflecting the sum of these direct and indirect employment levels.

Action Alternative 2C may have a relatively large economic impact in WIPP ROI due to the projected budget of $350 million per year, almost twice the levels observed during the 1988-1996 period. The relatively larger budget reflects waste treatment and storage costs for the CH-TRU waste inventory. Given the relatively larger scope of activities at the WIPP site, Action Alternative 2C has the potential of increasing the demand for government-provided goods and services (schools, police, fire protection, and health protection) within the ROI, as well as requiring additional capital investments in public infrastructure. Similarly, this subalternative would have the potential of increasing the level of activity within the local real estate market due to resulting changes in the WIPP ROI population and work force characteristics.

5.3.8 Transportation

This section describes the transportation impacts associated with the implementation of Action Alternatives 2A, 2B, and 2C. Descriptions of these alternatives are provided in Chapter 3.

Detailed results are presented for truck transportation. Rail transportation impacts adjusted from truck transportation results are presented in the final subsection for both the regular and dedicated rail options.

5.3.8.1 Route Characteristics and Shipment Projections

The methods used to determine route characteristics and the number of shipments for this alternative were identical to those presented in Section 5.1.8.1. Table 5-40 presents the number of shipments required under Action Alternatives 2A, 2B, and 2C.

Although the consolidation and treatment of waste would be different under each Action Alternative 2 subalternative than under the Proposed Action, those sites that would ship to WIPP would use the same routes. The one-way mileages from the treatment sites to WIPP, therefore, are the same as those presented for the Proposed Action in Table 5-5.

Table 5-40
Number of Truck Shipments to WIPP for Action Alternatives 2A, 2B, and 2C [a]

Waste Treatment Site	Action Alternative 2A			Action Alternative 2B			Action Alternative 2C		
	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total
CH-TRU Waste									
Argonne National Laboratory - East	---	---	---	---	---	---	22	---	22
Hanford Site	8,230	8,813	17,043	8,230	8,813	17,043	11,562	7,194	18,756
Idaho National Engineering and Environmental Laboratory/ANL-West	4,178	12,388	16,566	8,653	14,335	22,988	4,892	6,639	11,531
Lawrence Livermore National Laboratory	---	---	---	---	---	---	137	---	137
Los Alamos National Laboratory	2,952	1,947	4,899	---	---	---	4,236	1,590	5,826
Mound Plant	---	---	---	---	---	---	50	3	53
Nevada Test Site	---	---	---	---	---	---	73	---	73
Oak Ridge National Laboratory	---	---	---	---	---	---	192	8	200
Rocky Flats Environmental Technology Site	1,524	---	1,524	---	---	---	2,102	---	2,102
Savannah River Site	2,020	723	2,743	2,020	723	2,743	1,893	558	2451
Total CH-TRU Waste	18,904	23,871	42,775	18,903	23,871	42,774	25,159	15,992	41,151
RH-TRU Waste									
Hanford Site	17,730	1,031	18,761	17,730	1,031	18,761	17,730	1,031	18,761
Oak Ridge National Laboratory	2,057	1,077	3,134	2,057	1,077	3,134	2,057	1,077	3,134
Total RH-TRU Waste	19,787	2,108	21,895	19,787	2,108	21,895	19,787	2,108	21,895

[a] The total number of shipments under any of the subalternatives presented here do not include shipments from the generator sites to the consolidation sites. The number of consolidation shipments are: Subalternative 2A – 538 (CH-TRU waste), 8,254 (RH-TRU waste); Subalternative 2B – 8,466 (CH-TRU waste), 8,254 (RH-TRU waste); Subalternative 2C – 0 (CH-TRU waste), 8,254 (RH-TRU waste).

5.3.8.2 Accidents, Injuries, Fatalities, and Pollution-Related Health Effects from Truck Transportation

The following subsections present the number of nonradiological accidents, injuries, and fatalities expected under Action Alternatives 2A, 2B, and 2C. Table 5-41 presents a summary of these impacts as well as the pollution health effects (in fatalities), which are based upon the total miles traveled in urban areas and 9.9×10^{-8} fatalities per kilometer (1.6×10^{-7} per mile) (Rao et al. 1982). Also included in the results of Table 5-41 are the impacts due to TRU waste consolidation prior to thermal treatment. For additional details on the adjustment process, see Appendix E.

For Action Alternative 2A, the total number of nonradiological accidents, injuries and fatalities over the entire shipping campaign were estimated to be 109, 76, and 10, respectively. For Action Alternative 2B, the total numbers were 123 accidents, 86 injuries, and 11 fatalities. For Action Alternative 2C, the total numbers were 105 accidents, 74 injuries, and 11 fatalities, respectively.

Table 5-41
Nonradiological Impacts of Transporting TRU Waste by Truck for Action Alternatives 2A, 2B, and 2C

Impact	Action Alternative 2A			Action Alternative 2B			Action Alternative 2C		
	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total
CH-TRU Waste									
Number of Accidents	28	38	66	38	42	80	36	26	62
Number of Injuries	20	25	45	27	28	55	26	17	43
Number of Fatalities	3	3	6	4	4	8	4	3	7
Pollution Health Effects (fatalities)	0.09	0.1	0.2	0.1	0.1	0.2	0.1	0.08	0.2
RH-TRU Waste									
Number of Accidents	38	6	43	38	6	43	38	6	43
Number of Injuries	26	5	31	26	5	31	26	5	31
Number of Fatalities	4	1	4	4	1	4	4	1	4
Pollution Health Effects (fatalities)	0.1	0.03	0.1	0.1	0.03	0.1	0.1	0.03	0.2
Total									
Number of Accidents	66	44	109	76	48	123	74	32	105
Number of Injuries	46	30	76	53	33	86	51	22	74
Number of Fatalities	6	4	10	6	5	11	7	4	11
Pollution Health Effects (fatalities)	0.2	0.1	0.4	0.2	0.1	0.5	0.2	0.1	0.4

5.3.8.3 Accident-Free Radiological Impacts from Truck Transportation

The methods used to determine accident-free radiological impacts for Action Alternatives 2A, 2B, and 2C were identical to those used for the Proposed Action.

Table 5-42 presents a summary of the accident-free radiological impacts. For Action Alternative 2A, the total occupational and nonoccupational population doses would result in 0.5 LCF and 6.2 LCFs, respectively. For Action Alternative 2B, the total occupational and nonoccupational population doses estimated would result in 0.7 LCF and 6.9 LCFs, respectively. For Action Alternative 2C, the total occupational and nonoccupational population doses estimated would result in 0.5 LCF and 6.0 LCFs, respectively.

Table 5-42
Aggregate Accident-Free Population Radiological Impacts from Truck Transportation for Action Alternatives 2A, 2B, and 2C (LCFs) [a]

Impact	Action Alternative 2A			Action Alternative 2B			Action Alternative 2C		
	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total
CH-TRU Waste									
Occupational	0.2	0.2	0.4	0.3	0.3	0.6	0.2	0.2	0.4
Nonoccupational									
Stops	1.3	1.7	3.0	1.8	1.9	3.7	1.6	1.1	2.7
Sharing Route	0.07	0.09	0.2	0.1	0.1	0.2	0.09	0.06	0.2
Along Route	0.03	0.03	0.06	0.04	0.04	0.08	0.04	0.02	0.06
Nonoccupational - Total	1.4	1.8	3.2	1.9	2.0	3.9	1.8	1.2	3.0
RH-TRU Waste									
Occupational	0.1	0.02	0.1	0.1	0.02	0.1	0.1	0.02	0.1
Nonoccupational									
Stops	2.4	0.4	2.8	2.4	0.4	2.8	2.4	0.4	2.8
Sharing Route	0.1	0.03	0.1	0.1	0.03	0.1	0.1	0.03	0.1
Along Route	0.05	0.02	0.07	0.05	0.02	0.07	0.05	0.02	0.07
Nonoccupational - Total	2.6	0.5	3.0	2.6	0.5	3.0	2.6	0.5	3.0
Total CH-TRU and RH-TRU Waste									
Occupational	0.3	0.2	0.5	0.4	0.3	0.7	0.3	0.2	0.5
Nonoccupational									
Stops	3.7	2.1	5.8	4.2	2.3	6.5	4.0	1.5	5.5
Sharing Route	0.2	0.1	0.3	0.2	0.1	0.3	0.2	0.09	0.3
Along Route	0.08	0.05	0.1	0.09	0.06	0.2	0.09	0.04	0.1
Nonoccupational - Total	4.0	2.3	6.2	4.5	2.5	6.9	4.4	1.7	6.0

[a] Exposure during stops is based upon 50 individuals exposed at 20 meters. Stop time, in hours, is based upon 0.011d where d is the distance traveled in kilometers. These parameters are built into the RADTRAN code but substantially overestimate exposures from WIPP shipments. Because WIPP shipments would use two-driver teams (eliminating the need for overnight stops to sleep) and because the shipments would stop at sites chosen, in part, for their lack of population, the actual impacts from stops would be much lower.

As in Table 5-41, Table 5-42 includes the impacts from consolidation prior to the thermal LDR treatment. For details on the adjustment method, see Appendix E.

Table 5-43 summarizes the radiological impacts to maximally exposed individuals for TRU waste shipments under Action Alternatives 2A, 2B, and 2C. Section 5.1.8.3 and Appendix E describe the methods used to estimate the impacts presented in Table 5-43. The results in Table 5-43 indicate that the departure inspectors and state inspectors would have the greatest probability of an LCF.

Table 5-43
Radiological Impacts to MEIs from Truck Transportation
for Action Alternatives 2A, 2B, and 2C (Probability of an LCF)

Individual	Action Alternative 2A	Action Alternative 2B	Action Alternative 2C
CH-TRU Waste			
Stuck in traffic next to shipment	2.5E-6	2.5E-6	2.5E-6
Departure Inspector	6.8E-4	6.8E-4	7.6E-4
State Vehicle Inspector	1.7E-3	2.0E-3	1.6E-3
Residing adjacent to access route	1.5E-4	1.5E-4	1.5E-4
Rest stop employee	1.0E-4	1.0E-4	1.0E-4
RH-TRU Waste			
Stuck in traffic next to shipment	5.0E-6	5.0E-6	5.0E-6
Departure Inspector	2.2E-3	2.2E-3	2.2E-3
State Vehicle Inspector	2.9E-3	2.9E-3	2.9E-3
Residing adjacent to access route	2.0E-4	2.0E-4	2.0E-4
Rest stop employee	1.0E-4	1.0E-4	1.0E-4
Total CH-TRU and RH-TRU Waste			
Stuck in traffic next to shipment	7.5E-6	7.5E-6	7.5E-6
Departure Inspector	2.9E-3	2.9E-3	3.0E-3
State Vehicle Inspector	4.6E-3	4.9E-3	4.5E-3
Residing adjacent to access route	3.5E-4	3.5E-4	3.5E-4
Rest stop employee	2.0E-4	2.0E-4	2.0E-4

5.3.8.4 Radiological Impacts from Truck Transportation Accidents

Two types of analyses were conducted for SEIS-II radiological impacts due to accidents. The first type of analysis determined the radiological impact due to accidents during transportation from treatment or generator-storage sites to WIPP. This analysis took into account eight different severities of accidents, the number of miles from each site, and the number of shipments. The results of the analyses for route-specific accidents summed over the entire shipping campaign are presented in Table 5-44.

The second type of analysis was an assessment of four conservative, bounding accident scenarios. Two involving the breach of a TRUPACT-II, and two involving the breach of an RH-72B cask. Details on the estimation of impacts from these bounding case accidents are presented in Appendix E and in Section 5.1.8. For Action Alternatives 2A and 2B, the potential radiological releases from bounding case accidents that would occur after treatment would be smaller than those presented for the Proposed Action, with less than 1 LCF estimated. Those during consolidation for treatment would be similar to those presented for the Proposed Action. For Action Alternative 2C, the transportation impacts for RH-TRU waste that has been treated would be similar to those for Action Alternatives 2A and 2B. All of the impacts due to CH-TRU waste and due to consolidation of RH-TRU waste for treatment would be similar to the impacts presented for the Proposed Action.

Although the radionuclide inventory concentration for waste that is thermally treated increases by a factor of about 2.8, the thermal treatment of the waste reduces the release fraction for a bounding accident by a factor greater than 1,000. A release fraction is the quantity of material that would be released in an accident. The assumptions and methods used for these analyses are presented in Appendix E.

Table 5-44
Aggregate Radiological Population Impacts
by Truck for Action Alternatives 2A, 2B, and 2C (LCFs)

Origin	Action Alternative 2A			Action Alternative 2B			Action Alternative 2C		
	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total	Basic Inventory	Additional Inventory	Total
CH-TRU Waste									
Argonne National Laboratory-East	-----	-----	-----	-----	-----	-----	3.5E-4	-----	3.5E-4
Hanford Site	0.2	0.2	0.4	0.2	0.2	0.4	0.3	0.2	0.5
Idaho National Engineering and Environmental Laboratory/ANL-W	0.06	0.2	0.3	0.1	0.2	0.3	0.07	0.09	0.2
Lawrence Livermore National Laboratory	-----	-----	-----	-----	-----	-----	1.5E-3	-----	1.5E-3
Los Alamos National Laboratory	2.0E-3	1.5E-3	3.5E-3	-----	-----	-----	3.0E-3	1.0E-3	4.0E-3
Mound Plant	-----	-----	-----	-----	-----	-----	1.0E-3	5.0E-5	1.0E-3
Nevada Test Site	-----	-----	-----	-----	-----	-----	5.0E-4	-----	5.0E-4
Oak Ridge National Laboratory	-----	-----	-----	-----	-----	-----	2.5E-3	1.0E-4	2.5E-3
Rocky Flats Environmental Technology Site	5.0E-3	-----	5.0E-3	-----	-----	-----	7.0E-3	-----	7.0E-3
Savannah River Site	0.02	8.0E-3	0.03	0.02	8.0E-3	0.03	0.02	6.0E-3	0.03
RH-TRU Waste									
Hanford Site	0.02	1.5E-3	0.03	0.02	1.5E-3	0.03	0.02	1.5E-3	0.03
Oak Ridge National Laboratory	1.5E-3	1.0E-3	2.5E-3	1.5E-3	1.0E-3	2.5E-3	1.5E-3	1.0E-3	2.5E-3
Total CH-TRU and RH-TRU Waste									
Argonne National Laboratory-East	-----	-----	-----	-----	-----	-----	3.5E-4	-----	3.5E-4
Hanford Site	0.2	0.2	0.4	0.2	0.2	0.4	0.3	0.2	0.5
Idaho National Engineering and Environmental Laboratory/ANL-W	0.06	0.2	0.3	0.1	0.2	0.3	0.07	0.09	0.2
Lawrence Livermore National Laboratory	-----	-----	-----	-----	-----	-----	1.5E-3	-----	1.5E-3
Los Alamos National Laboratory	2.0E-3	1.5E-3	3.5E-3	-----	-----	-----	3.0E-3	1.0E-3	4.0E-3
Mound Plant	-----	-----	-----	-----	----	-----	1.0E-3	5.0E-5	1.0E-3
Nevada Test Site	-----	-----	-----	-----	-----	-----	5.0E-4	-----	5.0E-4
Oak Ridge National Laboratory	1.5E-3	1.0E-3	2.5E-3	1.5E-3	1.0E-3	2.5E-3	4.0E-3	1.0E-3	5.0E-3
Rocky Flats Environmental Technology Site	5.0E-3	-----	5.0E-3	-----	-----	-----	7.0E-3	-----	7.0E-3
Savannah River Site	0.02	8.0E-3	0.03	0.02	8.0E-3	0.03	0.02	6.0E-3	0.03
Total	0.3	0.4	0.7	0.3	0.4	0.7	0.4	0.3	0.7

5.3.8.5 Hazardous Chemical Impacts from Severe Truck Transportation Accidents to WIPP

During a severe accident, hazardous chemical releases under Action Alternatives 2A, 2B, and 2C would not pose a threat because the waste would have been thermally treated before being transported. Thermal treatment would eliminate the presence of all VOCs and greatly reduce the release fraction for heavy metals.

5.3.8.6 Impacts from Rail Transportation

This section presents a summary of transportation impacts for both the regular and dedicated rail transportation options. These impacts were estimated by scaling the transportation impacts from truck transportation to the impacts for rail transportation. In Appendix E, each of the impact parameters are identified, and the differences between truck and rail transportation are explained. Table 5-45 presents the estimated rail impacts for Action Alternatives 2A, 2B, and 2C.

Table 5-45
Impacts from Rail Transportation
for Action Alternatives 2A, 2B, and 2C

	Action Alternative 2A	Action Alternative 2B	Action Alternative 2C
Aggregate Traffic-Related Fatalities			
Regular Rail	5	6	6
Dedicated Rail	70	84	84
Aggregate Accident-Free Radiological Impacts (LCFs)			
CH-TRU Waste			
Occupational	0.02	0.03	0.02
Nonoccupational			
Stops	0.4	0.4	0.3
Sharing Route	1.7E-3	2.0E-3	1.6E-3
Along Route	0.09	0.1	0.09
Nonoccupational -Total	0.5	0.6	0.4
RH-TRU Waste			
Occupational	5.7E-3	5.7E-3	5.7E-3
Nonoccupational			
Stops	0.3	0.3	0.3
Sharing Route	1.6E-3	1.6E-3	1.6E-3
Along Route	0.1	0.1	0.1
Nonoccupational - Total	0.4	0.4	0.4
Total CH-TRU and RH-TRU Waste			
Occupational	0.03	0.03	0.03
Nonoccupational			
Stops	0.7	0.8	0.7
Sharing Route	3.3E-3	3.7E-3	3.2E-3
Along Route	0.2	0.2	0.2
Nonoccupational - Total	0.9	1.0	0.9
Aggregate Radiological Impacts from Rail Transportation Accidents (LCFs)			
CH-TRU Waste	0.7	0.7	0.7
RH-TRU Waste	0.03	0.03	0.03
Total CH-TRU and RH-TRU Waste	0.7	0.7	0.7

The analyses of bounding case accidents assumed similar accidents to those described in Section 5.2.8.6. For that waste treated thermally before shipment by train, the release fraction would be reduced by a factor of 1,000. However, thermal treatment increases the concentration of radionuclides by approximately a factor of 2.8. The combination of these two factors reduces the impacts for rail accidents to the following:

- For the accident with the conservative inventory in two breached TRUPACT-IIs, the total population dose under Action Alternatives 2A and 2B would result in 0.09 LCF in the exposed population. The estimated maximum individual dose would result in a 3×10^{-4} probability of a cancer fatality. Impacts for Action Alternative 2C would be the same as those presented for Action Alternative 1.

- For the accident with a conservative inventory in two breached RH-72Bs, the total population dose would result in 0.09 LCF in the exposed population. The estimated maximum individual dose would result in a 3×10^{-4} probability of a cancer fatality.

- For the accident with average concentrations of radionuclides in two breached TRUPACT-IIs, approximately 0.02 LCF in the exposed population would be expected under Action Alternatives 2A and 2B. The estimated maximum individual dose under these two subalternatives would result in a 2×10^{-4} probability of a cancer fatality. Impacts for Action Alternative 2C would be the same as those presented for Action Alternative 1.

- For the accident with average concentrations of radionuclides in two breached RH-72B casks, the total population dose would result in an expectation of 2×10^{-4} LCF in the population. The estimated maximum individual dose would result in a 4×10^{-6} probability of a cancer fatality.

5.3.9 Human Health Impacts from Waste Treatment, Storage, and Disposal Operations

This section presents human health impacts to the public, noninvolved workers, and involved workers from waste treatment, lag storage, and WIPP disposal operations under Action Alternatives 2A, 2B, and 2C. Impacts from waste treatment were adjusted from those presented in the WM PEIS, and a description of this adjustment is provided in Appendix B. Impacts from lag storage at the treatment sites (including WIPP under Action Alternative 2C) and WIPP disposal operations were estimated using the general methods and assumptions used for the human health analyses of the Proposed Action and Action Alternative 1. Action Alternative 2 is the only action alternative that eliminates the risk from storage of PCB-commingled TRU waste at the three sites known to store such waste (242 cubic meters [8,550 cubic feet] at Hanford, 461 cubic meters [16,300 cubic feet] at INEEL, and 19 cubic meters [670 cubic feet] at Mound). All VOCs in the waste under these subalternatives would be destroyed during thermal treatment, and all heavy metals would be immobilized. Therefore, no routine releases of hazardous chemicals would occur in subsequent lag storage or WIPP disposal operations. Thermal treatment also concentrates the waste and radionuclides into a smaller, more dense volume. Denser waste matrices tend to decrease surface dose rates because of more self-absorption of the external radiation emitted by radionuclides in the waste. Worker radiological impacts reflect the impact of these factors. Appendix F provides additional information on the methods used to determine the impacts from lag storage and WIPP disposal operations.

5.3.9.1 Public

Impacts to the populations and to the MEIs under Action Alternatives 2A, 2B, and 2C are presented in this section; results are presented in Table 5-46. Impacts from waste treatment, lag storage, and WIPP disposal operations are presented separately because different populations and individuals would be impacted by these activities. Waste treatment and lag storage would take place at six DOE sites under Action Alternative 2A, four sites under Action Alternative 2B, and three sites (including WIPP) under Action Alternative 2C. Waste disposal operations would take place only at WIPP.

Table 5-46
Lifetime Human Health Impacts to the Public from Waste Treatment, Lag Storage, and WIPP Disposal Operations for Action Alternatives 2A, 2B, and 2C

	Waste Treatment Impacts		Lag Storage Impacts		WIPP Disposal Operations Impacts	
Category	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)
MEI [b, c]						
Basic Inventory						
2A CH-TRU Waste	3E-5 (R)	3E-13 (L)	1E-7 (L)	0	5E-8	0
2B CH-TRU Waste	2E-5 (H)	3E-13 (I)	5E-9 (S)	0	5E-8	0
2C CH-TRU Waste	1E-4 (W)	3E-13 (W)	5E-8 (W)	0	5E-8	0
RH-TRU Waste	4E-7 (O)	1E-11 (O)	1E-9 (H)	0	7E-10	0
2A Total Waste	3E-5 (R)	1E-11 (O)	1E-7 (L)	0	5E-8	0
2B Total Waste	2E-5 (H)	1E-11 (O)	5E-9 (S)	0	5E-8	0
2C Total Waste	1E-4 (W)	1E-11 (O)	5E-8 (W)	0	5E-8	0
Total Inventory						
2A CH-TRU Waste	3E-5 (R)	5E-13 (I)	2E-7 (L)	0	1E-7	0
2B CH-TRU Waste	5E-5 (H)	6E-13 (I)	1E-8 (S)	0	1E-7	0
2C CH-TRU Waste	2E-4 (W)	5E-13 (W)	1E-7 (W)	0	1E-7	0
RH-TRU Waste	6E-7 (O)	2E-11 (O)	2E-9 (H)	0	8E-10	0
2A Total Waste	3E-5 (R)	2E-11 (O)	2E-7 (L)	0	1E-7	0
2B Total Waste	5E-5 (H)	2E-11 (O)	1E-8 (S)	0	1E-7	0
2C Total Waste	2E-4 (W)	2E-11 (O)	1E-7 (W)	0	1E-7	0
Population [c]						
Basic Inventory						
2A CH-TRU Waste	2.2	5E-9	7E-4	0	2E-5	0
2B CH-TRU Waste	1.1	2E-9	4E-4	0	2E-5	0
2C CH-TRU Waste	0.4	7E-10	2E-5	0	2E-5	0
RH-TRU Waste	0.02	2E-7	3E-5	0	9E-7	0
2A Total Waste	2.2	2E-7	7E-4	0	2E-5	0
2B Total Waste	1.1	2E-7	4E-4	0	2E-5	0
2C Total Waste	0.4	2E-7	5E-5	0	2E-5	0
Total Inventory						
2A CH-TRU Waste	2.3	9E-9	1E-3	0	5E-5	0
2B CH-TRU Waste	2.3	4E-9	6E-4	0	5E-5	0
2C CH-TRU Waste	0.9	1E-9	5E-5	0	5E-5	0
RH-TRU Waste	0.02	3E-7	5E-5	0	1E-6	0
2A Total Waste	2.4	3E-7	1E-3	0	5E-5	0
2B Total Waste	2.3	3E-7	6E-4	0	5E-5	0
2C Total Waste	0.9	3E-7	1E-4	0	5E-5	0
Aggregate Total						
2A	2.4	3E-7	1E-3	0	5E-5	0
2B	2.3	3E-7	8E-4	0	5E-5	0
2C	0.9	3E-7	3E-4	0	5E-5	0

[a] The probability of an LCF occurring to the MEI, and the number of LCFs in the population.
[b] H = Hanford, L = LANL, S = SRS, O = ORNL, R = RFETS, W = WIPP, I = INEEL
[c] The MEI and populations evaluated for treatment, storage, and operations impacts are different.

Note: Sites in parentheses indicate where the greatest MEI impact occurs.

Population impacts were estimated for those members of the public residing within 80 kilometers (50 miles) of all treatment sites, all lag storage sites, and at WIPP. The impacts to the MEIs from waste treatment and lag storage are presented for the highest individual waste treatment sites, while the impacts to the MEI from disposal operations are presented for an individual near WIPP. See Chapter 3 for additional information on where treatment and storage would occur.

Waste Treatment

Radiological impacts to the public from waste treatment under Action Alternatives 2A, 2B, and 2C would be 2.4, 2.3 and 0.9 LCFs, respectively, in the total population around the waste treatment sites. No cancer incidence would be expected in the total population from hazardous chemical exposure (3×10^{-7} cancers) under Action Alternatives 2A, 2B, and 2C. For radiological impacts, the MEI would be at RFETS under Action Alternative 2A (3×10^{-5} probability of an LCF), at Hanford under Action Alternative 2B (5×10^{-5} probability of an LCF), and at WIPP under Action Alternative 2C (2×10^{-4} probability of an LCF). Hazardous chemical impacts would not exceed a 2×10^{-11} probability of a cancer incidence at any site. No noncarcinogenic health effects are predicted. The maximum HIs for the MEIs would be 2×10^{-8} under Action Alternative 2A, 5×10^{-9} under Action Alternative 2B, and 1×10^{-7} under Action Alternative 2C, and no health effect is predicted unless the HI is 1 or higher.

Lag Storage

Only radiological impacts would result from lag storage because VOCs would be removed by thermal treatment under Action Alternatives 2A, 2B, and 2C. No LCFs would be expected in the total population around the lag storage sites under any of the alternatives, with 1×10^{-3}, 6×10^{-4}, and 1×10^{-4} LCFs expected under Action Alternatives 2A, 2B, and 2C, respectively. The MEI would be at LANL for Action Alternative 2A (2×10^{-7} probability of an LCF), at SRS for Action Alternative 2B (1×10^{-8} probability of an LCF), and at WIPP for Action Alternative 2C (1×10^{-7} probability of an LCF). No noncarcinogenic health effects would occur because there would be no exposure to hazardous chemicals.

The aggregate total indicated in Table 5-46 refers to the impacts to the public expected over the entire operational period under Action Alternative 2. Lag storage impact estimates conservatively assume that the lag storage period is equivalent to the disposal operations period, which is estimated to be 22 years for CH-TRU waste and 150 years for RH-TRU waste. No LCFs (a maximum of 1×10^{-3} LCFs under Action Alternative 2A) are expected over the several generations that would be exposed to the small potential routine releases of radioactive or hazardous materials.

WIPP Disposal Operations

Only radiological impacts would result from disposal operations at WIPP because VOCs would be removed by thermal treatment. No LCFs would be expected in the population around WIPP from radiation exposure, with 5×10^{-5} LCFs expected under all three of the subalternatives.

The MEI was assumed to be located at the Land Withdrawal Area boundary, the closest point at which an individual could reside. The MEI would have a 1×10^{-7} probability of an LCF from radiation exposure under all three subalternatives. No noncarcinogenic health effects would occur because there would be no exposure to hazardous chemicals.

The aggregate total indicated in Table 5-46 refers to the impacts expected over the entire operational period to the public residing within 80 kilometers (50 miles) at the WIPP site. The operational period for the disposal of the Total Inventory is expected to be 22 years for CH-TRU waste and 150 years for RH-TRU waste. No LCFs (5×10^{-5} LCFs) are expected to result from exposure to the estimated releases over the several generations.

5.3.9.2 Noninvolved Workers

Impacts to the noninvolved worker population and the maximally exposed noninvolved worker under Action Alternatives 2A, 2B, and 2C are presented in this section; results are presented in Table 5-47. A noninvolved worker is an employee who works at a site but is not directly involved in the treatment, storage, handling or disposal of waste. Impacts from waste treatment, lag storage, and WIPP disposal operations are presented separately because different noninvolved worker populations and individuals would be impacted by these activities. Waste treatment and lag storage would take place at six DOE sites under Action Alternative 2A, four sites under Action Alternative 2B, and three sites (including WIPP) under Action Alternative 2C. Waste disposal operations would take place only at WIPP.

The impacts to the maximally exposed noninvolved worker from waste treatment and lag storage are presented for the highest individual waste treatment sites. The maximally exposed noninvolved worker from disposal operations would be at the WIPP site and was assumed to work continuously at the location where emissions have the least atmospheric dispersion and thus the greatest potential impact. This location was 200 meters (660 feet) east of the exhaust filter building. The maximum ground-level concentrations of any airborne contamination would be expected at this location.

Waste Treatment

No LCFs would be expected in the total noninvolved worker population at the waste treatment sites, with 0.1, 0.1, and 0.06 LCFs under Action Alternatives 2A, 2B, and 2C, respectively. No cancer incidence would be expected in the total noninvolved worker population from hazardous chemical exposure, with 1×10^{-7} cancers under each of the three subalternatives. The maximally exposed noninvolved worker for radiological impacts would be at RFETS under Action Alternative 2A (5×10^{-5} probability of an LCF), at Hanford under Action Alternative 2B (2×10^{-4} probability of an LCF), and at WIPP under Action Alternative 2C (2×10^{-4} probability of an LCF). Hazardous chemical impacts would not exceed a 1×10^{-10} probability of a cancer incidence at any site. No noncarcinogenic health effects are predicted. The maximum HIs for the maximally exposed noninvolved worker would be 2×10^{-7} under Action Alternative 2A, 1×10^{-7} under Action Alternative 2B, and 8×10^{-7} under Action Alternative 2C, and no health effects are predicted unless the HI is 1 or higher.

Lag Storage

Only radiological impacts would result from lag storage because VOCs would be removed by thermal treatment. No LCFs would be expected in the total noninvolved worker population at the lag storage sites under any of the alternatives, with 2×10^{-2}, 2×10^{-2}, and 4×10^{-4} LCFs expected under Action Alternatives 2A, 2B, and 2C, respectively. The maximally exposed noninvolved worker would be at SRS for Action Alternatives 2A and 2B (1×10^{-6} probability of an LCF), and at WIPP for Action Alternative 2C (1×10^{-7} probability of an LCF). No noncarcinogenic health effects would occur because there would be no exposure to hazardous chemicals.

Table 5-47
Lifetime Human Health Impacts to Noninvolved Workers from Waste Treatment, Lag Storage, and WIPP Disposal Operations for Action Alternatives 2A, 2B, and 2C

Category	Waste Treatment Impacts		Lag Storage Impacts		WIPP Disposal Operations Impacts	
	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)
Maximally Exposed Noninvolved Worker [b, c]						
Basic Inventory						
2A CH-TRU Waste	5E-5 (R)	1E-12 (I)	8E-7 (S)	0	8E-8	0
2B CH-TRU Waste	7E-5 (H)	2E-12 (I)	8E-7 (S)	0	8E-8	0
2C CH-TRU Waste	1E-4 (W)	2E-12 (W)	8E-8 (W)	0	8E-8	0
RH-TRU Waste	3E-7 (O)	6E-11 (O)	1E-8 (H)	0	2E-9	0
2A Total Waste	5E-5 (R)	6E-11 (O)	8E-7 (S)	0	8E-8	0
2B Total Waste	7E-5 (H)	6E-11 (O)	8E-7 (S)	0	8E-8	0
2C Total Waste	1E-4 (W)	6E-11 (O)	8E-8 (W)	0	8E-8	0
Total Inventory						
2A CH-TRU Waste	5E-5 (R)	4E-12 (I)	1E-6 (S)	0	2E-7	0
2B CH-TRU Waste	2E-4 (H)	4E-12 (I)	1E-6 (S)	0	2E-7	0
2C CH-TRU Waste	2E-4 (W)	3E-12 (W)	1E-7 (W)	0	2E-7	0
RH-TRU Waste	5E-7 (O)	1E-10 (O)	2E-9 (H)	0	2E-9	0
2A Total Waste	5E-5 (R)	1E-10 (O)	1E-6 (S)	0	2E-7	0
2B Total Waste	2E-4 (H)	1E-10 (O)	1E-6 (S)	0	2E-7	0
2C Total Waste	2E-4 (W)	1E-10 (O)	1E-7 (W)	0	2E-7	0
Population [c]						
Basic Inventory						
2A CH-TRU Waste	0.09	3E-9	2E-2	0	9E-5	0
2B CH-TRU Waste	0.06	3E-9	2E-2	0	9E-5	0
2C CH-TRU Waste	0.03	3E-10	7E-5	0	9E-5	0
RH-TRU Waste	4E-4	7E-8	2E-4	0	2E-6	0
2A Total Waste	0.09	7E-8	2E-2	0	9E-5	0
2B Total Waste	0.06	7E-8	2E-2	0	9E-5	0
2C Total Waste	0.03	7E-8	3E-4	0	9E-5	0
Total Inventory						
2A CH-TRU Waste	0.1	7E-9	2E-2	0	2E-4	0
2B CH-TRU Waste	0.1	6E-9	2E-2	0	2E-4	0
2C CH-TRU Waste	0.06	7E-10	2E-4	0	2E-4	0
RH-TRU Waste	6E-4	1E-7	2E-4	0	2E-6	0
2A Total Waste	0.1	1E-7	2E-2	0	2E-4	0
2B Total Waste	0.1	1E-7	2E-2	0	2E-4	0
2C Total Waste	0.06	1E-7	4E-4	0	2E-4	0
Aggregate Total						
2A	0.1	1E-7	2E-2	0	2E-4	0
2B	0.1	1E-7	2E-2	0	2E-4	0
2C	0.06	1E-7	1E-3	0	2E-4	0

[a] The probability of an LCF occurring to the maximally exposed noninvolved worker, and the number of LCFs in the population.
[b] H = Hanford, I = INEEL, L = LANL, O = ORNL, R = RFETS, S = SRS, W = WIPP, I = INEEL
[c] The noninvolved workers considered for treatment, lag storage, and operations impacts are different.

Note: Sites in parentheses indicate where the greatest MEI impact would occur.

The aggregate total indicated in Table 5-47 refers to the impacts to noninvolved workers expected over the entire operational period under Action Alternative 2. Lag storage impact estimates conservatively assume that the lag storage period is equivalent to the disposal operations period, which is estimated to be 22 years for CH-TRU waste and 150 years for RH-TRU waste. No LCFs (a maximum of 0.02 LCFs under Action Alternatives 2A and 2B) are expected over the several generations that would be exposed to the small potential routine releases of radioactive or hazardous materials under incident-free operations.

WIPP Disposal Operations

Only radiological impacts would result from disposal operations at WIPP because VOCs would be removed by thermal treatment. No LCFs would be expected in the noninvolved worker population at WIPP from radiation exposure, 2×10^{-4} LCFs under all three subalternatives. All 1,095 WIPP employees were assumed to be exposed at the same level as the maximally exposed noninvolved worker. The maximally exposed noninvolved worker would have a 2×10^{-7} probability of an LCF from radiation exposure under all three subalternatives. No noncarcinogenic health effects would occur because there would be no exposure to hazardous chemicals.

The aggregate total indicated in Table 5-47 shows that no LCFs (2×10^{-4} LCFs) are expected in the multiple noninvolved worker populations that would be exposed to potential radioactive releases over the entire WIPP disposal operations period under Action Alternative 2.

5.3.9.3 Involved Workers

Impacts to involved workers under Action Alternatives 2A, 2B and 2C are presented in this section. Results are presented in Table 5-48, and additional information is presented in Appendix F. All worker exposures to radiation and hazardous chemicals would be controlled to ALARA levels. Administrative controls such as worker and area monitoring, rotation of workers to reduce exposures, and standard operating procedures would be used to limit exposures.

Waste Treatment

Under Action Alternative 2, radiological impacts to the involved worker population from waste treatment would be greater than nonradiological impacts. A maximum of 1.7, 1.3, and 0.6 radiation-related LCFs could occur in the worker population under Action Alternatives 2A, 2B, and 2C, respectively, while no cancer incidence (6×10^{-5}, 9×10^{-5}, and 8×10^{-5} cancers, respectively) would be expected from hazardous chemical exposure. No noncarcinogenic health effects are predicted because the maximum exposure index for a waste treatment worker under any of the subalternatives would be 6×10^{-3} under Action Alternatives 2A and 2B and 5×10^{-3} under Action Alternative 2C, and no health effect is predicted unless the HI is 1 or higher.

Lag Storage

Lag storage would take place under all three subalternatives. Assuming 35 years of management of the entire inventory, radiological impacts to the lag storage involved worker population would be less than 0.4 LCF under each subalternative. No hazardous chemical impacts, either carcinogenic or noncarcinogenic, would occur because of the removal of VOCs from the waste during thermal treatment. Involved worker lag storage impacts would be larger from CH-TRU

Table 5-48
Lifetime Human Health Impacts to Involved Workers from Waste Treatment, Lag Storage, and WIPP Disposal Operations for the Action Alternative 2 Subalternatives [a]

Category	Waste Treatment Impacts		Lag Storage Impacts		WIPP Disposal Operations Impacts	
	Radiological (LCF)	Hazardous Chemical (Cancer Incidence)	Radiological (LCF)	Hazardous Chemical (Cancer Incidence)	Radiological (LCF)	Hazardous Chemical (Cancer Incidence)
Population						
Basic Inventory					(36 workers)	(36 workers)
2A CH-TRU Waste	0.7	2E-5	0.09	0	0.1	0
2B CH-TRU Waste	0.5	4E-5	0.08	0	0.1	0
2C CH-TRU Waste	0.02	3E-5	0.08	0	0.1	0
RH-TRU Waste	0.2	9E-6	≤0.09	0	≤0.1	0
2A Total Waste	0.9	3E-5	≤0.2	0	≤0.2	0
2B Total Waste	0.7	5E-5	≤0.2	0	≤0.2	0
2C Total Waste	0.3	4E-5	≤0.2	0	≤0.2	0
Total Inventory					(36 workers)	(36 workers)
2A CH-TRU Waste	1.4	5E-5	0.2	0	0.2	0
2B CH-TRU Waste	1.1	8E-5	0.2	0	0.2	0
2C CH-TRU Waste	0.3	1E-5	0.2	0	0.2	0
RH-TRU Waste	0.3	1E-5	≤0.2	0	≤0.2	0
2A Total Waste	1.7	6E-5	≤0.4	0	≤0.4	0
2B Total Waste	1.3	9E-5	≤0.4	0	≤0.4	0
2C Total Waste	0.6	8E-5	≤0.4	0	≤0.4	0
Aggregate Total						
2A	1.7	6E-5	0.01	0	< 0.4	0
2B	1.3	9E-5	0.02	0	< 0.4	0
2C	0.6	8E-5	0	0	< 0.4	0

[a] The workers considered for treatment impacts, lag storage impacts, and operations impacts are different.

waste storage operations than from RH-TRU waste storage operations. Impacts from RH-TRU waste lag storage operations would be less because of remote RH-TRU waste handling and greater administrative controls for RH-TRU waste. Lag storage impacts would be assessed in future site-wide or project-specific NEPA reviews.

The impacts from CH-TRU waste would be from the external radiation dose received during waste container handling. Potential radiological impacts from inhalation of radioactive gases released from waste containers would be negligible. Involved worker impacts from lag storage were calculated by assuming waste handlers would spend 2 hours every workday at 1 meter (3.3 feet) from the CH-TRU waste containers and were assumed to be exposed over a 35-year career. Container dose rates were decay-corrected over 35 years and 20 percent of the Total Inventory were assumed to be monitored annually.

The aggregate total indicated in Table 5-48 refers to the impacts to involved workers at the lag storage sites over the entire operational period under Action Alternative 2. Lag storage impact estimates conservatively assume that the lag storage period is equivalent to the disposal operations period, which is estimated to be 22 years for CH-TRU waste and 150 years for RH-TRU waste. Fewer than 0.4 LCFs would be expected over the several generations of involved workers that would be exposed externally from lag storage operations. The radiological impact estimates reflect the aggregate impacts analyses presented in detail in Appendix F.

WIPP Disposal Operations

Radiological impacts to the involved worker population at WIPP from disposal operations would be less than 0.4 LCF for each subalternative. WIPP involved worker radiological impact estimates were made assuming each involved worker handled the CH-TRU waste for 400 hours per year. The operational period was determined by assuming that 2.5 years of disposal operations were required to fill each panel. Impacts to involved workers from RH-TRU waste handling were assumed to be the same or less than those from CH-TRU waste handling. This assumption is conservative because RH-TRU waste is typically handled using remote-handling equipment, workers are usually protected by radiation shielding, and stricter administrative procedures are used. The impact from handling RH-TRU waste, therefore, would probably be less than the impact from handling CH-TRU waste. No hazardous chemical impacts, either carcinogenic or noncarcinogenic, would occur because of the removal of VOCs from the waste during thermal treatment.

The aggregate total indicated in Table 5-48 refers to the impacts to WIPP involved workers from incident-free operations over the entire disposal operations period under Action Alternative 2. Fewer than 0.4 LCFs from external radiation exposures would be expected over several generations of involved workers at WIPP. Radiological impacts over the entire operational period would be approximately twice the number of impacts estimated for the maximally exposed population during the first 35 years of CH-TRU waste disposal operations. Radiological decay would reduce the radiological impacts to each generation of WIPP workers.

5.3.10 Facility Accidents

This section describes potential consequences of facility accidents at the treatment sites from thermal treatment of waste, from waste storage after treatment but before shipment to WIPP, and at WIPP from waste management and disposal. Consequences of treatment and storage were evaluated at seven treatment sites (Hanford, LANL, INEEL, SRS, RFETS, ORNL, and WIPP); these seven sites would treat and store all of the CH-TRU and RH-TRU waste under the Action Alternative 2 subalternatives. The difference between Action Alternatives 2A and 2B is that no CH-TRU waste treatment and storage (and no consequences) would occur at LANL and RFETS under Action Alternative 2B. CH-TRU waste treatment and storage would occur only at WIPP under Action Alternative 2C.

Inhalation would be the dominant exposure pathway for accidental releases of radionuclides and hazardous chemicals. Radiological consequences are potentially much greater than hazardous chemical consequences and are dominated by inhalation of transuranic radionuclides. Details of the methods and assumptions used and complete accident descriptions and results are provided in Appendix G.

5.3.10.1 Waste Treatment Accidents

Three potential waste treatment accidents were evaluated for the Action Alternative 2 subalternatives; they are shown in Table 5-49. The results are presented only for accidents involving CH-TRU waste. The results from these accidents would be greater than results on similar accidents involving RH-TRU waste because CH-TRU waste contains a higher concentration of transuranic radionuclides.

Table 5-49
Treatment Accident Scenarios Evaluated
for the Action Alternative 2 Subalternatives

Accident Scenarios	Annual Occurrence Frequency	Description
Drum Failure (Accident Scenario T4)	0.01	Cover block falls on a drum filled with hot glass causing shattering of glass.
Steam Explosion (Accident Scenario T5)	1E-4	Steam explosion in glass melter causes fragmentation of glass.
Earthquake (Accident Scenario T6)	1E-5 or less	A beyond-design-basis earthquake (or other natural event) collapses the roof, causing drums to rupture and HEPA filters to fail.

The potential accident consequences under Action Alternatives 2A and 2B were evaluated in detail for the five major sites that would treat and store the greatest volume of CH-TRU waste: Hanford, INEEL, LANL, RFETS, SRS for Action Alternatives 2A and 2B. Under Action Alternative 2C, consequences were evaluated at WIPP for the treatment of CH-TRU waste.

Treatment accidents analyzed include a high-frequency/low-consequence operational accident which is expected to be applicable under any facility design, a low-frequency/high-consequence operational accident, and a beyond-design-basis natural disaster accident. Accident analysis information is presented in Appendix G.

Estimated radiological consequences are presented as the number of LCFs in the exposed population and the probability of an LCF occurring in MEIs. Carcinogenic and noncarcinogenic consequences from hazardous chemicals, both VOCs and heavy metals, were estimated. Carcinogenic consequences are presented as the number of cancers in the exposed population and the probability of cancer for MEIs. Noncarcinogenic consequences from exposure to VOCs and heavy metals were estimated by two different methods for the drum failure and steam explosion scenarios (Accident Scenarios T4 and T5, respectively): IDLH-equivalent ratios and ERPG ratios. Only IDLH-equivalent ratios were calculated for the catastrophic treatment facility failure of the earthquake (Accident Scenario T6). The potential noncarcinogenic consequences identified by ERPG ratios would be of minor importance during such a catastrophic event and its consequent site-operations upheaval.

In general, potential radiological consequences were found to be higher than hazardous chemical consequences, which would be very small for most accident cases. Estimated results for members of the public, the maximally exposed noninvolved worker, and the maximally exposed involved worker are presented below and in Table 5-50. Consequences to the maximally exposed involved worker are addressed qualitatively.

The potential radiological consequences from RH-TRU waste treatment accidents are greatest at the ORNL site for all accident scenarios and receptors; however, they are four to five orders of magnitude less than the consequences from CH-TRU waste treatment accidents.

Table 5-50
Radiological Consequences of Treatment Accidents
for the Action Alternative 2 Subalternatives

Accident Scenarios		Population (Number of LCFs)	MEI (probability of an LCF)	Maximally Exposed Noninvolved Worker (probability of an LCF)
CH-TRU Waste	Drum Failure (Accident Scenario T4)	Maximum: 1E-3 (RFETS)	Maximum: 5E-7 (LANL)	Maximum: 1E-6 (Hanford)
	Steam Explosion (Accident Scenario T5)	Maximum: 0.2 (RFETS)	Maximum: 8E-5 (LANL)	Maximum: 2E-4 (Hanford/LANL)
	Earthquake (Accident Scenario T6)	Hanford: 440 INEEL: 25 LANL: 180 RFETS: 480 SRS: 42 WIPP: 28	Hanford: 0.4 INEEL: 0.01 LANL: 0.6 RFETS: 0.03 SRS: 5E-3 WIPP: 1	Hanford: 1 INEEL: 1 LANL: 1 RFETS: 1 SRS: 1 WIPP: 1
RH-TRU Waste	Drum Failure (Accident Scenario T4)	Maximum: 4E-8 (ORNL)	Maximum: 3E-11 (ORNL)	Maximum: 4E-11 (ORNL)
	Steam Explosion (Accident Scenario T5)	Maximum: 7E-6 (ORNL)	Maximum: 5E-9 (ORNL)	Maximum: 6E-9 (ORNL)
	Earthquake (Accident Scenario T6)	Hanford: 1E-2 ORNL: 2E-2	Hanford: 5E-6 ORNL: 2E-5	Hanford: 3E-5 ORNL: 5E-5

Note: This table presents estimates of the consequences of accident scenarios and does not reflect the frequency (or probability) of the accident occurring.

Public

Under Action Alternatives 2A and 2B, population consequences from treatment accidents were estimated for the exposed populations around the six treatment sites. Potential consequences to the population and MEIs at the six sites vary over a wide range because of differences in the population distributions, distances to MEIs, and atmospheric dispersion factors among the sites. No LCFs would be expected in the exposed population from the drum failure or steam explosion scenarios (Accident Scenarios T4 or T5, respectively), but 480 and 440 LCFs were estimated to occur from the earthquake (Accident Scenario T6) at RFETS and Hanford, respectively. Due to the events of the earthquake scenario, 180, 42, and 25 LCFs were estimated at LANL, SRS, and INEEL, respectively. The radiological consequences to the MEI were estimated to be the highest at LANL for all three accidents. Consequences to the MEI due to the earthquake or other natural phenomenon (Accident Scenario T6) were found to range from a 5×10^{-3} (at SRS) to 0.6 (at LANL) probability of an LCF.

Under Action Alternative 2C, population consequences from treatment accidents were estimated for the exposed population around the WIPP site. The radiological population consequences for the drum failure, steam explosion, and earthquake scenarios (Accident Scenarios T4, T5, and T6, respectively) would be 5×10^{-5}, 9×10^{-3}, and 28 LCFs, respectively. Consequences to the MEI due to the earthquake (Accident Scenario T6) were estimated to be 1 probability of an LCF to the MEI at the WIPP site.

For the Action Alternative 2 subalternatives, all carcinogenic consequences from the drum failure or steam explosion (Accident Scenarios T4 and T5, respectively) would be attributable to heavy metals because VOCs would be consumed by the fire or thermal treatment. Under Action Alternatives 2A and 2B, no cancers were estimated to occur in the exposed population from the hazardous chemical releases of any accident. The maximum probability of cancer to the MEI would be 4×10^{-9} from any of the three treatment accidents. The MEIs at all sites could develop irreversible or severe health effects from both metals (lead and mercury) and VOCs (1,1,2,2-tetrachlorethane) released during the earthquake. Life threatening effects could be expected at all sites but SRS from beryllium. Under Action Alternative 2C, no cancers were estimated to occur in the exposed population from the hazardous chemical releases of any accident. The probability of cancer to the WIPP MEI would be 2×10^{-7} from hazardous chemical releases during the earthquake.

Under Action Alternatives 2A, 2B, and 2C, RH-TRU waste would be treated at Hanford and ORNL. Consequences under Accident Scenarios T4, T5, and T6 would be bounded by those presented for CH-TRU waste treatment. The maximum population consequence (20 LCFs) would be expected at ORNL under Accident Scenario T6. The maximum probability of an LCF (0.02) would also be at ORNL. No cancer incidents would be expected in the population as a result of exposure to hazardous chemicals from any accident scenarios. Irreversible or severe health effects would be expected for both the ORNL and Hanford MEI as a result of the earthquake.

Maximally Exposed Noninvolved Worker

Under Action Alternatives 2A and 2B, the maximally exposed noninvolved worker was assumed to be at the location of greatest consequence outside of the waste treatment building. The estimated consequences to the noninvolved worker would not vary significantly across the six sites. Radiological consequences to the maximally exposed noninvolved worker would result in a 1×10^{-6} probability of an LCF from the events of the drum failure scenario (Accident Scenario T4), a 2×10^{-4} probability of an LCF from the events of the steam explosion scenario (Accident Scenario T5), and a maximum probability of 1 LCF (at all sites) from the events caused by the beyond-design-basis earthquake (Accident Scenario T6).

No cancers would be expected from the release of hazardous chemicals or metals from any of the accidents; the greatest probability of cancer would be 2×10^{-8}. During the earthquake (Accident Scenario T6), the noninvolved workers at all of the sites have a chance of developing noncarcinogenic irreversible or severe health effects, and life threatening effects were estimated for all sites INEEL. These effects would be expected from exposures to both VOCs and heavy metals. Under Action Alternative 2C, the only effects due to hazardous chemicals or metals were estimated under the earthquake accident (Accident Scenario T6) where the noninvolved worker would develop irreversible health effects from exposure to 1,1,2,2-tetrachloroethane, mercury, and lead and may expect life threatening effects from beryllium, mercury and lead.

Under Action Alternative 2, RH-TRU waste would be processed at ORNL and Hanford. The maximum consequence from RH-TRU waste treatment would be about 2 percent of that listed for CH-TRU waste treatment. The radiological consequence to the noninvolved worker would be a 0.04 probability of an LCF for Accident Scenario T6. Consequences from hazardous chemicals would be equal to those described above in the discussion for CH-TRU waste treatment.

Maximally Exposed Involved Worker

For all of the Action Alternative 2 subalternatives, no consequences to the maximally exposed involved worker would be anticipated from either the drum failure or steam explosion accidents (Accident Scenarios T4 or T5, respectively). These accidents are such that involved workers would be able to evacuate immediately or would not be affected by the events. Substantial consequences would be possible from the earthquake (Accident Scenario T6), including workers killed by debris from collapsing treatment facilities and radiation doses from TRU waste being treated. Intakes of VOCs, and heavy metals would also be expected.

5.3.10.2 Waste Storage Accidents

Two potential waste storage accidents were evaluated under the Action Alternative 2 subalternatives and are described in Table 5-51. The drum fire (Accident Scenario S2) analyzed under Action Alternative 1 is not credible for thermally treated waste because waste treatment would remove all combustible components. The results are presented only for accidents involving CH-TRU waste because the would be greater than the results for similar accidents involving RH-TRU waste. However, the consequences from catastrophic failure of an RH-TRU waste storage facility as a result of an earthquake are presented in Appendix G.

Table 5-51
Storage Accident Scenarios Evaluated
for the Action Alternative 2 Subalternatives

Accident Scenarios	Annual Occurrence Frequency	Description
Drum Puncture, Drop, and Lid Failure (Accident Scenario S1) [a]	1E-2 to 1E-4	A forklift strikes and punctures a drum on a lower level of a stack in the storage facility. The stack is destabilized and two drums fall to the ground and lose their lids upon impact.
Drum Fire (Accident Scenario S2)	---	Not credible for thermally treated waste.
Earthquake (Accident Scenario S3)	1E-5 or less	A beyond design-basis earthquake (or other natural event) occurs, causing the collapse of the building.

[a] Occurrence frequency for Accident Scenario S1 was taken from reference documents applicable to waste packaged to meet the planning-basis WAC. The quantity of waste handled would be lower under this alternative and frequency of occurrence would likely be lower as well.

Lower transuranic radionuclide activity in RH–TRU waste (lower PE-Ci levels, see Table G-23 and Table G-24), lower RH-TRU waste volume, more robust waste containers for RH-TRU waste, and presumably more robust construction of RH-TRU waste storage facilities (thick concrete walls for external radiation shielding) all combine to limit potential consequences from RH-TRU waste accidents. Waste would be stored at Hanford, INEEL, RFETS, ORNL (RH-TRU waste only), and SRS under Action Alternative 2A; at Hanford, INEEL, ORNL (RH-TRU waste only) and SRS under Action Alternative 2B; and at WIPP, ORNL (RH-TRU waste only), and Hanford (RH-TRU waste only) under Action Alternative 2C. Consequences at a particular site were analyzed only for the subalternative that would result in the greatest potential consequences.

Storage accidents analyzed include a high-frequency/low-consequence operational accident which is expected to be applicable under any facility design (Accident Scenario S1) and a beyond-design-basis natural disaster accident (Accident Scenario S3). For Accident Scenarios S1 and S2, CH-TRU waste involved in the accidents was assumed to have the maximum radionuclide levels allowable under the planning-basis WAC (80 PE-Ci per drum), conservative concentrations of VOCs (based on CH-TRU sampling and WAC limits), and conservative concentrations of heavy metals. Accident Scenario S3 involves a large number of waste containers; therefore, site-specific drum PE-Ci values and average hazardous chemical concentrations were used in the analyses. Additional details on the accident analyses are presented in Appendix G.

Estimated radiological consequences are presented as the number of LCFs in the exposed population and the probability of an LCF occurring in the MEI. Carcinogenic and noncarcinogenic consequences from heavy metals were estimated. Carcinogenic consequences are presented as the number of cancers in the exposed population and the probability of cancer for MEIs. Noncarcinogenic consequences from exposure to heavy metals were estimated by two different methods for the drum puncture (Accident Scenario S1): IDLH-equivalent ratios and ERPG ratios. Only IDLH-equivalent ratios were calculated for the catastrophic storage facility failure of the earthquake (Accident Scenario S3). The potential noncarcinogenic consequences identified by ERPG ratios would be of minor importance during such a catastrophic event and its consequent site-operations upheaval.

In general, potential radiological consequences would be higher than hazardous chemical consequences, which are very small for most accident cases. Estimated results for members of the public, the maximally exposed noninvolved worker, and the maximally exposed involved worker are presented below and in Table 5-52.

Table 5-52
Radiological Consequences of Storage Accidents for the Action Alternative 2 Subalternatives [a]

Accident Scenarios	Population (number of LCFs)	MEI (probability of an LCF)	Maximally Exposed Noninvolved Worker (probability of an LCF)
Drum Puncture and Lid Failure (Accident Scenario S1)	Maximum: 3E-5 (RFETS)	Maximum: 1E-8 (WIPP)	Maximum: 2E-8 (Hanford, LANL)
Earthquake (Accident Scenario S3)	Hanford: 9 INEEL [b]: 0.8 LANL [c]: 2 RFETS [c]: 10 SRS: 2 WIPP [d]: 2	Hanford: 5E-3 INEEL [b]: 4E-4 LANL [c]: 4E-3 RFETS [c]: 7E-4 SRS: 2E-4 WIPP [d]: 0.08	Hanford: 0.03 INEEL [b]: 0.05 LANL [c]: 0.02 RFETS [c]: 0.02 SRS: 0.04 WIPP [d]: 0.1

[a] The site with the greatest consequence is shown in parentheses.
[b] Consequences are greatest at INEEL under Action Alternative 2B.
[c] CH-TRU waste is stored at LANL and RFETS only under Action Alternative 2A.
[d] CH-TRU waste is stored at WIPP only under Action Alternative 2C.

Note: This table presents estimates of the consequences of accident scenarios and does not reflect the frequency (or probability) of the accident occurring.

Public

Population consequences from storage accidents were estimated for the exposed populations around the six treatment sites. Potential consequences to the population and MEIs at the six sites vary over a wide range because the population distributions, distances to MEIs, and atmospheric dispersion factors vary from site to site. No LCFs would be expected in the exposed population from the drum puncture accident (Accident Scenario S1), but LCFs were estimated to occur from the earthquake (Accident Scenario S3) at almost all sites; the LCFs would range from 0.8 (at INEEL) to 10 (at RFETS). The radiological consequences to the MEI would be highest for the WIPP MEI under the drum puncture scenario (Accident Scenario S1), with a 1×10^{-8} probability of an LCF. Consequences from the earthquake scenario (Accident Scenario S3) were estimated to range from a 2×10^{-4} (at SRS) to 0.08 (at WIPP) probability of an LCF to the MEI.

No cancers would be expected in the exposed population from the heavy metal releases of any accident. The maximum probability of cancer incidence to the MEI from the heavy metal releases of either accident would be 2×10^{-7} (Accident Scenario S3 at WIPP). No noncarcinogenic consequences would be expected from either accident.

Maximally Exposed Noninvolved Worker

The maximally exposed noninvolved worker was assumed to be at the location of greatest consequence outside of the waste storage facility. The consequences to the noninvolved worker were estimated to vary over a narrow range. The range was narrow because of the uniform release heights assumed and the close distances considered for all noninvolved workers.

Radiological consequences to the maximally exposed noninvolved worker would result in a 2×10^{-8} probability of an LCF from the events of the drum puncture scenario (Accident Scenario S1) and up to a 0.05 probability of an LCF (at INEEL under Action Alternative 2B) from the events of the beyond-design-basis earthquake scenario (Accident Scenario S3).

For hazardous chemical consequences, the maximum probability of cancer to the maximally exposed noninvolved worker from heavy metal intakes would be 5×10^{-16} from the drum puncture scenario (Accident Scenario S1). The corresponding consequence for the earthquake scenario (Accident Scenario S3) would be 2×10^{-8} probability of cancer. No noncarcinogenic consequences would be expected from any accident release.

Maximally Exposed Involved Worker

The involved worker would be the individual most seriously affected by the two accidents analyzed. Consequences were quantitatively estimated for the drum puncture scenario (Accident Scenario S1). The maximally exposed involved worker could potentially have a 3×10^{-3} probability of an LCF as a result of the radionuclide intake due to the events of the drum puncture scenario. The analysis assumed the instantaneous radioactive material releases from the three containers, expanding in a uniform hemisphere 5 meters (16 feet) in radius. The worker was assumed to inhale this air for 1 minute prior to exiting to a fresh air source. The involved worker could have a 6×10^{-11} probability of cancer from estimated hazardous chemical intakes due to the drum puncture accident (Accident Scenario S1). No noncarcinogenic consequences would be expected.

Catastrophic destruction of the storage facility due to an earthquake (Accident Scenario S3) could result in death or serious injury to the maximally exposed involved worker due to falling debris and releases from stored waste.

5.3.10.3 WIPP Disposal Accidents

Seven potential accidents at WIPP during disposal operations were evaluated for the Action Alternative 2 subalternatives; they are shown in Table 5-53. Because thermal treatment would eliminate the combustibility of the waste, Accident Scenario W5, a drum fire, is not credible and was not evaluated. Five of the accidents involve only CH-TRU waste (Accident Scenarios W1 through W4 and W7), one involves only RH-TRU waste (Accident Scenario W8), and one was evaluated for consequences from CH-TRU and RH-TRU waste (Accident Scenario W6). Annual accident frequencies are one-half those of other alternatives because of the smaller waste volumes and the limited amount of waste that could be placed in each panel due to the thermal power limitation of the WIPP underground.

Potential radiological consequences are substantially higher than consequences from heavy metals, which are very small for all accident cases. There would be no VOCs in thermally treated waste, and VOCs were the primary contributors to hazardous chemical consequences (though small) under the Proposed Action and Action Alternative 1. Estimated results for members of the public, the maximally exposed noninvolved worker, and the maximally exposed involved worker are presented below.

Table 5-53
WIPP Disposal Accident Scenarios
for the Action Alternative 2 Subalternatives

Accident Scenarios	Annual Occurrence Frequency	Description
Drop, Lid Failure in Waste Handling Building (Accident Scenario W1)	5E-3	A package of drums is dropped in the Waste Handling Building, a drum on top of the package falls and its lid seal fails.
Drop, Puncture Lid Failure in Waste Handling Building (Accident Scenario W2)	5E-3	Forklift strikes and punctures drums on lower level of stack in the Waste Handling Building. A drum on the upper level falls and the lid seal fails.
Drop, Lid Failure in Underground (Accident Scenario W3)	5E-3	Same as accident W1, but it occurs in the underground.
Drop, Puncture, Lid Failure in Underground (Accident Scenario W4)	5E-3	Same as accident 2, but it occurs in the underground.
Container Fire (Accident Scenario W5)	---	Not credible for thermally treated waste.
Hoist Failure (Accident Scenario W6)	<1E-6	Waste hoist braking system fails and fully loaded hoist falls to the bottom of shaft. Both CH-TRU and RH-TRU waste loads were evaluated.
Roof Fall (Accident Scenario W7)	5E-3, Panel 1 <1E-6, other panels	A portion of a disposal room roof falls prior to panel closure, crushing drums and causing lid seal failures.
RH-TRU Canister Breach (Accident Scenario W8)	5E-5 to 5E-7	RH-TRU waste canister is breached during Waste Handling Building operations.

With the exception of the waste hoist failure (Accident Scenario W6), the consequences of postulated accidents under the Action Alternative 2 subalternatives would be less than those under the Proposed Action by at least a factor of ten. Thermal treatment also eliminates potential consequences of an RH-TRU container breach (Accident Scenario W8). In such an event, thermally treated waste would be less likely to release particles of respirable size. However, in the event of a hoist failure, the more uniform, brittle waste matrix (as compared to waste treated to planning-basis WAC) is more likely to shatter upon impact into respirable particles. The thermal treatment also concentrates the heavy metals in the waste form, which also increases the potential consequences. Consequences of the hoist failure are approximately five to seven times higher than those estimated for waste treated to planning-basis WAC under the Proposed Action and Action Alternative 1. Radiological consequences of accidents under the Action Alternative 2 subalternatives are shown in Table 5-54.

Public

Population consequences from WIPP disposal accidents were estimated for the 22.5 degree sector west of the site, which includes the City of Carlsbad. The population in this sector is 25,629 and would be affected greater than any other section in the surrounding 80-kilometer (50-mile) region. Consequences to the MEI were evaluated at the point of closest public access to the DOE Exclusive Use Area boundary and the least atmosphere dispersion of facility exhaust ventilation air, which would be the location of maximum consequence. This point was 300 meters (990 feet) south of the Exhaust Filter Building. No credit was taken for HEPA filtration of accident releases from either the Exhaust Filter Building or the Waste Handling Building.

Table 5-54
Radiological Consequences of WIPP Disposal Accidents for the Action Alternative 2 Subalternatives

Accident Scenarios	Population (LCFs)	MEI (probability of LCF)	Maximally Exposed Noninvolved Worker (probability of LCF)	Maximally Exposed Involved Worker (probability of LCF)
Drop, Lid Failure in Waste Handling Building (Accident Scenario W1)	9E-4	1E-5	1E-5	3E-3
Drop, Puncture Lid Failure in Waste Handling Building (Accident Scenario W2)	9E-4	1E-5	1E-5	3E-3
Drop, Lid Failure in Underground (Accident Scenario W3)	9E-4	1E-5	1E-5	3E-3
Drop, Puncture, Lid Failure in Underground (Accident Scenario W4)	9E-4	1E-5	1E-5	3E-3
Container Fire (Accident Scenario W5)	Not Credible	Not Credible	Not Credible	Not Credible
Hoist Failure (both CH-TRU and RH-TRU waste) (Accident Scenario W6)	CH-TRU: 29 RH-TRU: 9	CH-TRU: 0.6 RH-TRU: 0.1	CH-TRU: 0.5 RH-TRU: 0.1	See Footnote a
Roof Failure (Accident Scenario W7)	0.02	2E-4	2E-4	See Footnote a
RH-TRU Waste Canister Breach (Accident Scenario W8)	0	0	0	0

[a] These consequences could range from negligible (workers not present, or warned of the falling hoist and evacuated) to catastrophic (all workers in the immediate vicinity killed by accident debris)

Note: This table presents estimates of the consequences of accident scenarios and does not reflect the frequency (or probability) of the accident occurring.

Radiological consequences from accidents would be higher than consequences from heavy metals. The accident with the largest potential radiological consequence to the population and the MEI would be the failure of a fully loaded waste hoist (Accident Scenario W6). Up to 29 LCFs could occur in the exposed population, and the MEI could experience a 0.6 probability of an LCF. The hoist failure accident would also result in the highest potential carcinogenic heavy metal consequence, with an estimated 4×10^{-7} cancers occurring in the exposed population and an estimated 5×10^{-9} probability of cancer for the MEI. No fatalities due to hazardous chemical effects would be expected under any accident scenario.

Maximally Exposed Noninvolved Worker

The maximally exposed noninvolved worker at WIPP was assumed to be located at the location of least atmospheric dispersion, 300 meters (990 feet) south of the Exhaust Filter Building, which is the same location as the MEI. The stack that exhausts the underground ventilation is elevated and, as a result, the location of least plume dispersion is some distance from the release point. Radiological consequences (shown in Table 5-54) may be slightly lower than those for the MEI because of the small different in the radiation dose-to-LCF conversion factors for workers and members of the public. Consequences from exposure to heavy metals would be identical to those of the MEI.

Maximally Exposed Involved Worker

The potentially highest consequences to an involved worker would be underground, from failure of a fully loaded waste hoist (Accident Scenario W6) or roof fall (Accident Scenario W7). These consequences could range from negligible (workers not present, or warned of the falling hoist and evacuated) to catastrophic (all workers in the immediate vicinity killed by accident debris). Four workers would be expected to be routinely involved in underground operations and potentially at risk from these accidents.

Radiological consequences of accidents to the maximally exposed involved worker from noncatastrophic accidents are shown in Table 5-54. Consequences would come from the drop and lid failure (Accident Scenarios W1 and W3) and drum puncture accidents (Accident Scenarios W2 and W4), all with a 3×10^{-3} probability of an LCF. The highest heavy metal carcinogenic consequences to an involved worker were estimated to be a 6×10^{-11} probability of a cancer incidence. No fatalities due to toxicological effects would be expected.

5.3.11 Industrial Safety

A total of nine, seven, and six fatalities would occur under Action Alternatives 2A, 2B, and 2C, respectively, from industrial accidents during waste treatment at all treatment sites. These estimates were adjusted from the physical-hazard fatality estimates of the WM PEIS.

Under Action Alternatives 2A, 2B and 2C, WIPP operational activities would be essentially the same as those conducted under the Proposed Action but would last approximately 150 years rather than 35 years. Decommissioning activities would be the same as those for the Proposed Action. Estimated industrial safety impacts to workers under Action Alternatives 2A, 2B, and 2C are presented in Table 5-55. Oversight and inspections by the MSHA and adherence to OSHA regulations would likely reduce actual occurrences below these estimated values.

Table 5-55
Industrial Safety Impacts from WIPP Operations and Decommissioning for the Action Alternative 2 Subalternatives

Years	Injury/Illness			Fatalities		
	Excavation	Operations	Total	Excavation	Operations	Total
Operations 1998-2148	93	5,250	5,343	0.2	5.2	5.4
Decommissioning 2148-2158	187	96	283	0.3	0.1	0.4
Total	280	5,346	5,626	0.5	5.3	5.8

5.3.12 Long-Term Performance

This section presents the potential impacts associated with the long-term performance of the WIPP repository for Action Alternative 2 evaluated for the 10,000-year period after the site is closed. These impacts were estimated based on computer simulations that predicted radionuclide and heavy metal releases from TRU waste in the repository under undisturbed and disturbed conditions. Analyses were conducted using the same methods as for the Proposed Action and other action alternatives; additional information is presented in Appendix H. The waste volume emplaced would be 107,000 cubic meters (3.8 million cubic feet) of CH-TRU waste and 19,000 cubic meters (671,000 cubic feet) of RH-TRU waste. The repository size was increased from the 10 panels of the Proposed Action to 75 panels to accommodate the increased waste volume. The radionuclide inventory was increased to 7.3×10^6 Ci in CH-TRU waste and 5.1×10^6 Ci in RH-TRU waste, essentially the same as the inventories of Action Alternatives 1 and 3. There were similar increases in heavy metal inventories. Detailed information on the radionuclide and heavy metal inventories is provided in Appendix A.

The four cases below were analyzed for Action Alternative 2. The cases are the same as the Proposed Action and other action alternatives but include alternative-specific differences, such as repository size and radionuclide and heavy metal inventories.

- Case 11 considered undisturbed repository performance. Median parameter values were used for input variables where probability distributions have been defined.

- Case 12 considered disturbed conditions resulting from a borehole assumed to pass through the repository and intercept a pressurized brine reservoir in the Castile Formation. Median parameter values were used for input variables where probability distributions have been defined.

- Case 13 was the same as Case 11 but used 75th percentile parameter values for input variables where probability distributions have been defined.

- Case 14 was the same as Case 12 but used 75th percentile parameter values for input variables where probability distributions have been defined.

5.3.12.1 Impacts of Undisturbed Conditions

Radionuclide and heavy metal (predominantly lead) migration for undisturbed conditions at 10,000 years after closure for Case 13 (75th percentile parameter values) is presented in Figure 5-5. Case 13 resulted in slightly more extensive migration than Case 11 (median parameter values). Figure 5-5 shows the locations in the modeled region where the concentration of total radionuclide activity in the brine, summed over 30 radionuclides, is equal to 1 pCi per liter (1×10^{-9} Ci per cubic meter). A total heavy metal concentration of one part per billion (1×10^{-3} milligrams per cubic meter) showed approximately the same extent of migration from the repository as the one pCi per liter level of total radionuclide activity concentration.

Approximately the same vertical and lateral migration of radionuclides and heavy metals would occur for Action Alternative 2 as for the Proposed Action. Total radionuclide concentrations of one pCi per liter would extend about 20 meters (65 feet) below the repository, about 40 meters (130 feet) above the repository, and about 1,900 meters (6,200 feet) laterally.

Analysis of undisturbed repository conditions (Cases 11 and 13) during the first 10,000 years showed that no radionuclides or heavy metals would be released to the Culebra Dolomite. No total radionuclide activity concentrations greater than 1 pCi per liter or heavy metal concentrations greater than 1 part per billion would be found beyond the 5-kilometer (3-mile) subsurface lateral boundary. There would be no release to the accessible environment and therefore no human health impact. Additional information is provided in Appendix H.

5.3.12.2 Impacts of Disturbed Conditions

This section presents the impacts of two exposure scenarios evaluated for disturbed conditions of Action Alternative 2**.**

Surface Release Caused by Drilling into the Repository

The human health impacts of drilling into the repository (Case 12 and Case 14) were evaluated for a drilling crew member and a well-site geologist. These individuals were assumed to be exposed to waste material brought to the land surface by drilling, as described in Section 5.1.12.2 and Appendix H. For Action Alternative 2, 12 waste panels would hold only CH-TRU waste and 63 panels would hold only RH-TRU waste, so a drilling event could contact either CH-TRU waste or RH-TRU waste but not both.

The estimated radionuclide release to the ground surface for Case 12 (median parameter values) totaled 0.8 and 0.02 Ci for intrusions into CH-TRU waste and RH-TRU waste, respectively. For Case 14 (75th percentile parameter values), the estimated radionuclide releases totaled 1.0 Ci and 0.02 Ci, respectively. The releases would consist mainly of Pu-238, Pu-239, and Am-241 for all of these events. For Case 12, total heavy metal releases would be 1.9 and 3.4 kilograms (4.2 and 7.5 pounds) from CH-TRU waste and RH-TRU waste, respectively. For Case 14, the releases would be 2.3 and 4.2 kilograms (5.1 and 9.3 pounds), respectively. Additional information is provided in Appendix H.

The radiological impacts to a drilling crew member for Case 12 (median parameter values) would be a 5×10^{-5} and 1×10^{-6} probability of an LCF, respectively, from drilling intrusions of CH-TRU waste and RH-TRU waste. For Case 14 (75th percentile parameter values), the probability of an

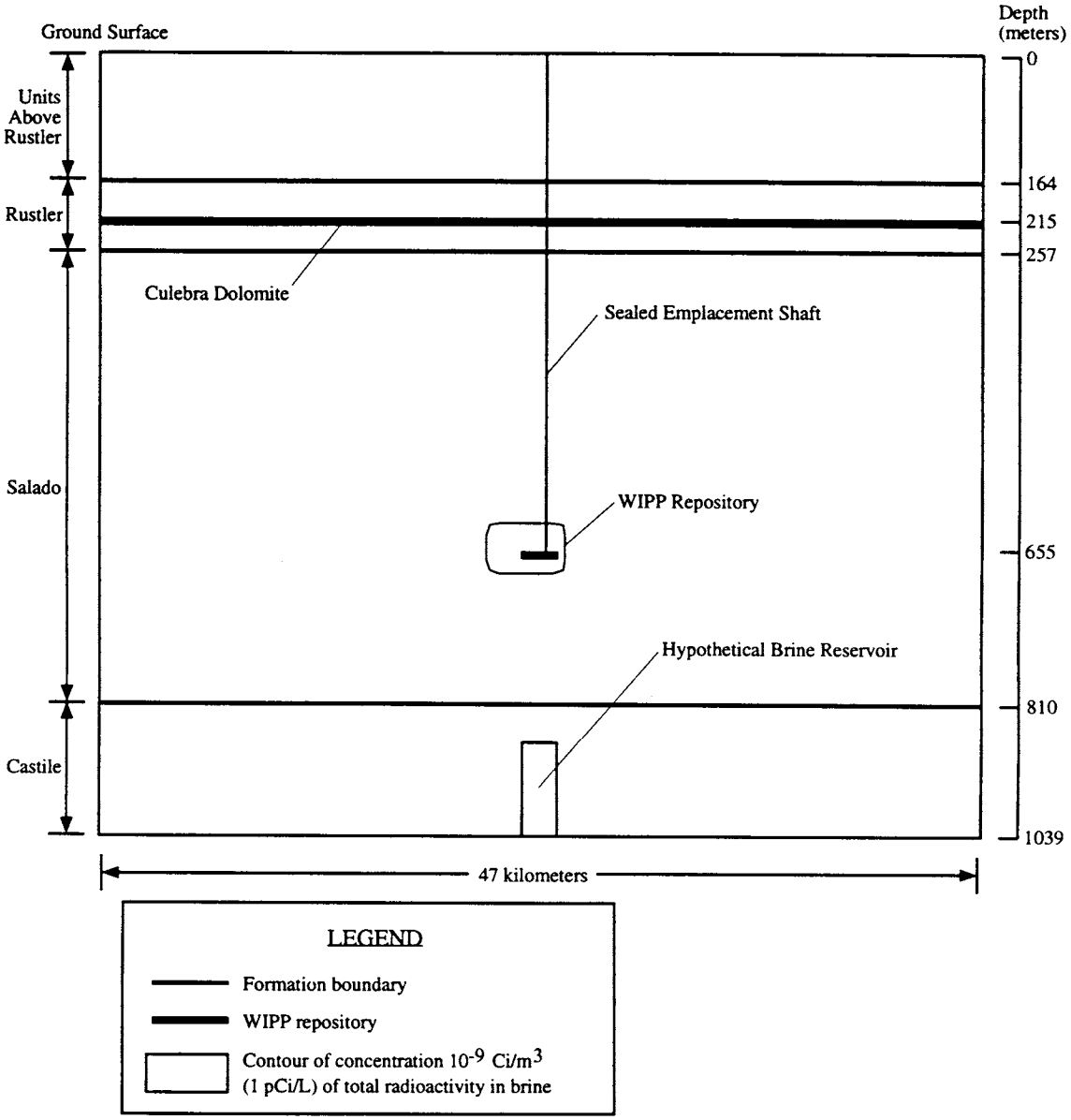


Figure 5-5
Extent of Radionuclide Migration at 10,000 Years with Undisturbed Conditions Using 75th Percentile Parameter Values (Case 13) for Action Alternative 2

LCF would be 1 x 10^{-4} and 2 x 10^{-6} for the same respective intrusions. The majority of the impacts would be due to the inadvertent ingestion of drill cuttings (ranging from about 90 to 99 percent), with lesser impact from external radiation dose. Americium-241 would be the major dose contributor. Ingestion of heavy metals for this scenario would result in a 3.2 x 10^{-8} and 8.5 x 10^{-10} probability of cancer incidence for intrusions in CH-TRU waste and RH-TRU waste, respectively. There would be no noncarcinogenic impacts expected from the ingestion of the metals because all hazard indices would be much less than one. There would be no VOCs in waste disposed of under Action Alternative 2 and thus no impacts.

Radiological impacts to the well-site geologist from external radiation exposure for Case 12 (median parameter values) would result in a 6 x 10^{-9} probability of an LCF from CH-TRU waste and a 4 x 10^{-9} probability of an LCF from RH-TRU waste. For Case 13 (75th percentile parameter values), the radiological impacts would be a 7 x 10^{-9} probability of an LCF from CH-TRU waste and a 1 x 10^{-8} probability of an LCF from RH-TRU waste. Am-241 and U-234 were major external dose contributors in CH-TRU and RH-TRU waste for Case 12 and in CH-TRU waste for Case 14, while Sr-90 and Cs-137 were the major external dose contributors in RH-TRU waste for Case 14.

Drilling through the Repository into a Pressurized Brine Reservoir

Impacts of drilling through the repository into a pressurized brine reservoir were analyzed as described in Section 5.1.12.2 and in Appendix H, using information specific to Action Alternative 2 where appropriate. Analysis of radionuclide and heavy metal migration for this scenario within 10,000 years after closure for Case 12 (median parameter values) showed there would be no radionuclide or heavy metal releases into the Culebra Dolomite or the accessible environment.

The extent of radionuclide (predominantly Pu-238, Pu-239, and Am-241) migration for disturbed conditions at 10,000 years after closure for Case 14 (75th percentile parameters values) is presented schematically in Figure 5-6. Total radionuclide activity concentrations of 1 pCi per liter are shown. Simulations showed radionuclides migrated upward and downward into the borehole and penetrated into rocks directly in contact with the borehole for a limited distance. For Case 14 only, migration extends upward into the Culebra Dolomite at 10,000 years. Migration also extends downward in the borehole (for both Cases 12 and 14) to the Castile Formation and into the brine reservoir. This would occur after the initial pressure in the pressurized brine pocket dissipates and equilibrates with pressures in the repository and overlying units penetrated by the borehole. A total heavy metal concentration of one part per billion (1 x 10^{-3} milligrams per cubic meter) showed approximately the same extent of migration from the repository as the 1 pCi per liter level of total radionuclide activity concentration. Predicted brine pressures and additional modeling information is provided in Appendix H.

Impacts of radionuclide and heavy metal migration to the accessible environment were evaluated for Case 14 (75th percentile parameter values) since a release of contaminants into the Culebra Dolomite was indicated for this case only. The exposure scenario was the same as evaluated for the Proposed Action and other action alternatives, for an individual consuming beef from cattle using the water from a stock well 3 kilometers (2 miles) from the point of intrusion. Results are presented only for partial mining conditions, since calculated impacts for full mining conditions were significantly lower (see Section H.8.2). Radiological impacts would be negligible, with a 7 x 10^{-28} probability of an LCF. The dominant dose contributor was Pu-239. Ingestion of heavy

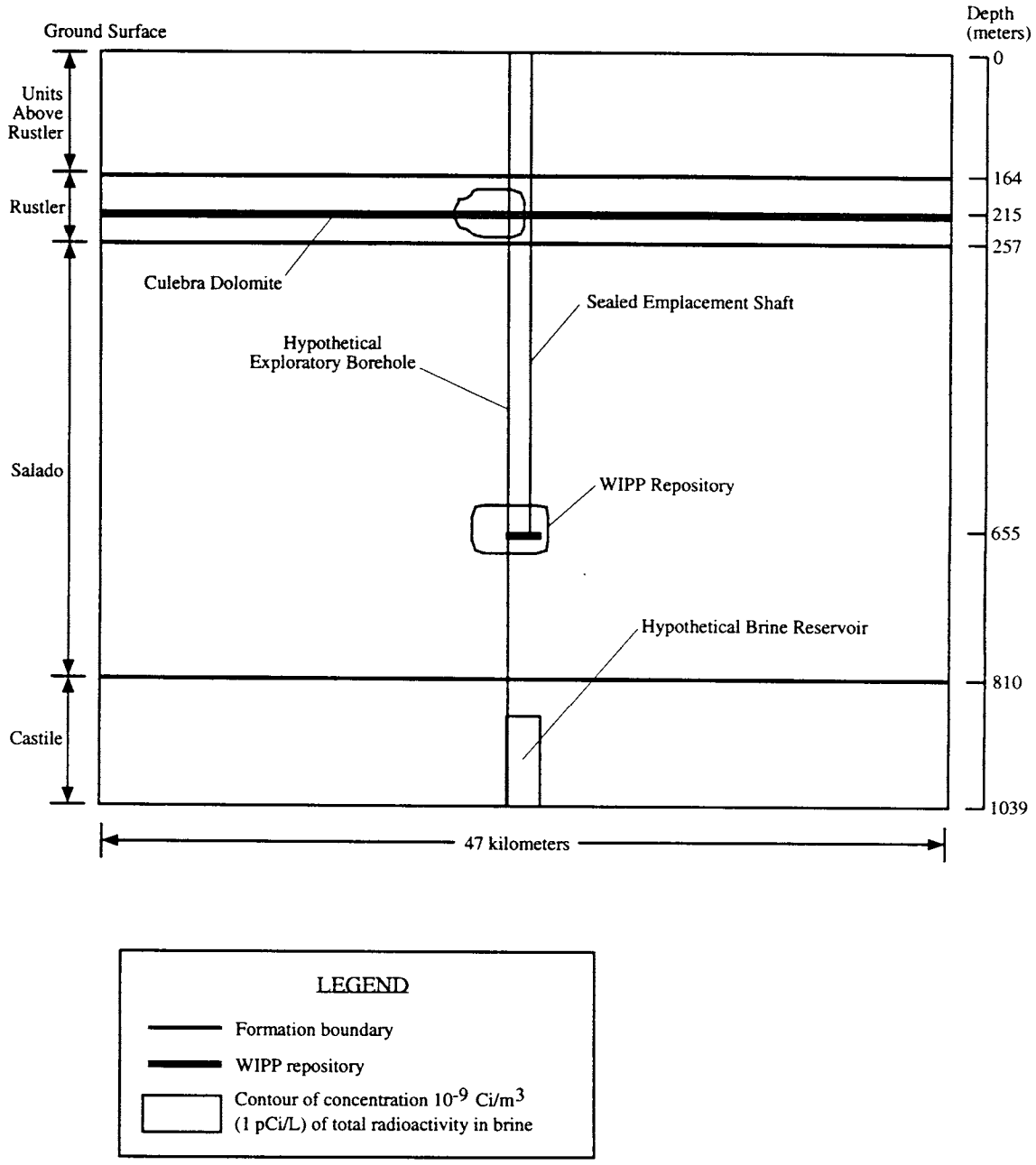


Figure 5-6
Extent of Radionuclide Migration at 10,000 Years with Disturbed Conditions Using 75th Percentile Parameter Values (Case 14) for Action Alternative 2

metals from consumption of contaminated beef was also found to result in negligible impacts, with a probability of cancer incidence of 3×10^{-27}. No noncarcinogenic impacts would be expected. There would be no VOCs in waste disposed of under Action Alternative 2 and thus no impacts. Additional information is presented in Appendix H.

5.3.13 Reducing WIPP Operations for Action Alternative 2

As noted in Chapter 3, stakeholders requested a discussion in greater detail of the changes to impacts should the Department reduce the period of operations for WIPP under Action Alternative 2. The period of operations is 150 years, but it could be reduced to 70 years by constructing three new shafts and tripling the number of excavation and emplacement crews. Additional costs would total $24 million in capital costs and $155 million in annual operating costs.

As with Action Alternative 1, no additional impacts would be expected at treatment facilities because the facilities and their periods of operation would be identical to those discussed earlier. The time to ship to WIPP from the treatment facilities would decrease from 150 years to 58 years. The aggregate nonradiological impacts would be the same as those described earlier, except that they would occur within the shorter time period. The accident-free radiological impacts to occupational and nonoccupational populations were reported as aggregate impacts over the entire shipping campaign; therefore, no increase in impacts would be noted. However, because the MEIs would be exposed to more shipments, the estimated exposure to MEIs would increase by a factor of 2.6. All accident impacts would be identical to those described earlier.

Because the size of the WIPP underground facility would remain the same, land use, biological resource, air quality, and cultural resource impacts would be similar to those described earlier in this section. Noise impacts would triple because the rate of shipments through Carlsbad would triple. Water quality and infrastructure impacts may be impacted by the additional work crews.

Human health impacts would decrease for lag storage. The impacts to the public, noninvolved workers, and involved workers over the entire operations period would remain the same, but they would be compressed into one-third of the time. Impacts to the MEIs would triple because the waste that would be emplaced during a lifetime would triple. Industrial safety impacts would decrease by 40 percent, considering the reduced operation time, construction of the shafts, and the increased number of workers. There would be no change in long-term performance assessment results.

Life-cycle cost impacts would change the most. Should only trucks be used, life-cycle costs would drop from a low of $54.01 billion for Action Alternative 2A and a high of $57.18 billion for Action Alternative 2B in 1994 dollars ($19.56 billion and $21.19 billion discounted) to $41.11 billion and $44.27 billion, respectively ($13.46 billion and $14.50 billion discounted). Should regular rail transportation be used, life-cycle costs would decrease for these alternatives from $52.03 billion and $55.02 billion ($19.22 billion and $20.83 billion discounted) to $39.13 billion and $42.11 billion ($12.81 billion and $13.79 billion discounted). Should dedicated rail transportation be used, life-cycle costs would decrease for these alternatives from $57.88 billion and $61.36 billion ($20.21 billion and $21.90 billion discounted) to $44.98 billion and $48.45 billion ($14.73 billion and $15.87 billion discounted).

5.4 IMPACTS OF ACTION ALTERNATIVE 3

This section describes the environmental impacts associated with the implementation of Action Alternative 3. Under this alternative, WIPP would accept the Additional Inventory (except for PCB-commingled waste) as well as the Basic Inventory for disposal, and all of the waste would be treated by a shred and grout process. The total volume of waste to be treated under this alternative would be 312,000 cubic meters (11 million cubic feet) (see Tables 3-10 and 3-11). The operational time frame would extend to the year 2200 (190 years). A detailed description of Action Alternative 3 is given in Section 3.2.4.

5.4.1 Land Use and Management

Land use impacts at the treatment sites for Action Alternative 3 would be similar to those under the Proposed Action, discussed in Section 5.1.1. Additional waste would be treated under this alternative, but the treatment time period would be extended to 35 years, and the land requirements for the number and size of the treatment facilities would be about the same as for the Proposed Action. Treatment facilities would be located to avoid sensitive and inappropriate areas (including flood plains, known cultural resource areas, and the habitats of endangered or threatened species) (DOE 1997). Before treatment facilities would be constructed, further NEPA reviews would be undertaken at a site-wide or project-specific level.

Surface land use impacts during disposal operations under Action Alternative 3 would be similar to those under the Proposed Action, as discussed in Section 5.1.1 because the size of the surface facilities would be similar to those for the Proposed Action. A difference from the Proposed Action would be noted for decommissioning and closure; approximately 375 hectares (927 acres) would be affected due to an increased underground waste disposal area. As in the Proposed Action, the Land Withdrawal Area would be available to the public for nonintrusive surface activities following decommissioning and closure.

5.4.2 Air Quality

From TRU waste treatment, the only criteria pollutant postulated to exceed 10 percent of the applicable annual regulatory standard during operation of treatment facilities would be CO at RFETS (20 percent) (DOE 1997). RFETS, LLNL, NTS, and ANL-E are in nonattainment areas for some of the pollutants. In nonattainment areas, activities that introduce new sources of emissions are regulated under the General Conformity Rule. In attainment areas, regulations for the PSD of ambient air quality apply. In both cases, a permit is required for sources which will result in emissions equal to or greater than the limits set by pertinent regulations. No radiological, hazardous, or toxic air pollutants would exceed 10 percent of the applicable regulatory standard during normal treatment operations (DOE 1997). Potential minor emissions of PM_{10} may occur during construction.

At WIPP, potential air quality impacts from disposal operations under Action Alternative 3 would be similar to those anticipated under the Proposed Action. Although the volume of waste disposed of under this alternative would increase the duration of disposal activities, there would be no substantial difference in the rate of pollutant emissions on either an annual or short-term basis.

Potential air quality impacts due to the decommissioning of WIPP would be similar to those under the Proposed Action. Construction of the berm and permanent markers and other decommissioning

activities would last longer than under the Proposed Action but would probably produce no substantial increase in annual pollutant emissions.

5.4.3 Biological Resources

The biological impacts at the treatment sites under Action Alternative 3 would be the same as those for the Proposed Action. Additional waste would be treated, but the size and type of the treatment facilities would be similar to those discussed in Section 5.1.3. Also, construction and operation of the treatment facilities should not affect populations of nonsensitive plant and animal species. Terrestrial wildlife species probably would not be affected by airborne emissions or spills into aquatic environments due to traffic accidents (DOE 1997). Threatened and endangered species may be present at all of the proposed treatment sites; however, impacts to these species would depend on the actual location of the facility at a particular site. Site selection would be conducted following site-wide or project-level NEPA review and appropriate Endangered Species Act consultation, during which impacts would be assessed and mitigated, if necessary. During site selection critical habitats of species listed as threatened, endangered, or candidates would be avoided.

Federally listed, threatened and endangered, and state-listed species occur in Eddy County and potentially at the WIPP, although DOE has not observed threatened, endangered, or proposed species or critical habitats at the WIPP site during surveys conducted for recent biennial environmental compliance reports. DOE recently completed a site-specific biological survey, during which no endangered, threatened, or state-listed species were identified.

At WIPP, a total of 375 hectares (927 acres) of aboveground area would be affected by decommissioning, salt pile reclamation, closure, and construction of berms and permanent markers. These activities would disturb avian and small mammal habitat. The disturbed areas would probably be attractive as habitat after natural vegetation recolonizes.

5.4.4 Cultural Resources

At the treatment sites, cultural resource impacts are expected to be the same for this alternative as for the Proposed Action. Construction and operation of TRU waste management and treatment facilities could adversely affect cultural resources, but site-level cultural resource surveys would be conducted and protection measures established, where necessary, when specific facility construction locations are proposed. These surveys would be part of site-wide or project-level NEPA reviews.

At WIPP, TRU waste shipping and operational activities would not have an impact on the archaeological sites on the disturbed land; however, some sites could be affected by closure- and decommissioning-related activities. Measures for ensuring protection of known archaeological and historic resources (or others that may be inadvertently discovered during ground-disturbing activities) are discussed in the *Waste Isolation Pilot Plant Land Management Plan* (DOE 1996a). They include identifying, inventorying, evaluating, and treating cultural resources under the National Historic Preservation Act of 1966. DOE will avoid, to the maximum extent possible, sites found eligible for inclusion in the NRHP. Where avoidance is not possible, mitigation measures will be developed under the Joint Powers Agreement in consultation with the State Historic Preservation Office, Advisory Council on Historic Preservation, and the Bureau of Land Management (BLM).

5.4.5 Noise

The WM PEIS stated that treatment sites would probably be located in industrial areas along high-volume highway corridors; therefore, ambient noise levels are not likely to increase substantially. Still, some sensitive receptors may be affected (DOE 1997). Site-specific noise impacts will be assessed in site-wide or project-specific NEPA documents. Because all waste would travel to WIPP but only a portion of the waste would travel from or to each treatment facility, the greatest noise impacts due to transportation noise would be near the WIPP site.

At WIPP, potential noise impacts under Action Alternative 3 would be similar to those under Action Alternative 1 (Section 5.2.5). Like Action Alternative 1, the increase in noise associated with this alternative would be negligible when compared to the background noise level associated with normal automobile, truck, and rail traffic in Carlsbad, New Mexico.

5.4.6 Water Resources and Infrastructure

At the treatment sites, proposed TRU waste activities might affect on-site infrastructures although no off-site infrastructure impacts would be expected. The infrastructure elements analyzed were the capacity of on-site water, power, and wastewater systems, and on-site transportation. For Action Alternative 3, Hanford would have an increased on-site demand for wastewater treatment that would exceed 5 percent of the current demand (7 percent), and INEEL would have an increase in on-site demand for power by 6.4 percent (DOE 1997).

Minor impacts to the on-site transportation infrastructure under Action Alternative 3 may occur. These impacts would result from an increase to on-site employment of 7 percent at Hanford and INEEL and 8 percent at LANL. Impacts to the off-site transportation infrastructure are not anticipated because population increases would not exceed 5 percent. On-site increases could be accommodated by existing and anticipated water supplies, power, water treatment, and transportation systems (DOE 1997).

Negligible annual infrastructure impacts would occur at WIPP under Action Alternative 3. Existing water supply and sewer capabilities and existing and planned power and roadway resources will be able to accommodate proposed disposal operations.

5.4.7 Socioeconomics

Estimated life-cycle costs and potential socioeconomic impacts for Action Alternative 3 are presented in the following subsections.

5.4.7.1 Life-Cycle Costs

The life-cycle costs of Action Alternative 3 are presented in Table 5-56 and are discussed below. Six TRU waste treatment sites would process, treat, and package waste over a period of 35 years. In addition, the largest sites (INEEL, Hanford, and ORNL) would be required to store portions of their treated waste volumes over some or all of the 190-year period of disposal operations because of WIPP emplacement limitations. Life-cycle costs include an additional $640 million to account for treatment to planning-basis WAC of waste that would be shipped for treatment. The waste treatment facility life-cycle costs at these six sites would be $24.34 billion (in 1994 dollars).

Table 5-56
Life-Cycle Costs for Action Alternative 3 (in millions of 1994 dollars) [a]

Cost Information	Basic Inventory			Additional Inventory			Total	Total Discounted
	CH-TRU Waste	RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU Waste	RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU and RH-TRU Waste
Treatment Facilities	9,550	4,380	13,930	9,940	470	10,410	24,340	13,500
Transport by Truck	2,330	3,270	5,600	910	330	1,240	6,840	910
Transport by Regular Train	800	1,120	1,920	310	110	420	2,340	310
Transport by Dedicated Train	5,340	7,500	12,840	2,100	750	2,850	15,690	2,100
Disposal at WIPP	12,300	3,100	15,400	12,800	290	13,090	28,490	3,610
Total Life-Cycle Cost (Truck)	24,180	10,750	34,930	23,560	1,090	24,740	59,670	18,030
Total Life-Cycle Cost (Regular Train)	22,650	8,600	31,250	23,050	870	23,920	55,170	17,420
Total Life-Cycle Cost (Dedicated Train)	27,190	14,980	42,170	24,840	1,510	26,350	68,520	19,210

[a] The methods and assumptions used to estimate the various cost components are described in Appendix D. Actual totals may differ due to rounding.

Waste transport costs include one of three transportation options between the six consolidation sites and the WIPP site: (1) trucks, as in the Proposed Action, (2) trucks with maximum practical commercial rail, and (3) trucks with maximum practical dedicated rail. Under these options, transportation costs include the consolidation of the waste volumes at the six large sites, and then shipment to WIPP via truck or rail for emplacement. The waste transport costs would be about $6.84 billion by truck, $2.34 billion by regular rail, and $15.69 billion by dedicated rail.

The WIPP site life-cycle costs of the project would be projected to be $28.49 billion. The total life-cycle costs of Action Alternative 3 would be $59.67 billion ($18.03 billion when discounted) using trucks, $55.17 billion ($17.42 billion when discounted) using regular rail, and $68.52 billion ($19.21 billion when discounted) using dedicated rail.

5.4.7.2 Economic Impacts

TRU waste treatment activities would support direct, indirect, and induced jobs. Action Alternative 3 would support approximately 24,900 jobs in the ROIs of the six treatment sites (Hanford, INEEL, LANL, ORNL, RFETS, and SRS).

Estimates of the impacts of Action Alternative 3 on employment, income, and the production of goods and services within the ROI are presented in Table 5-57. These regional impacts were estimated using an annual average project budget of $180 million per year over a 190-year period of waste disposal operations. Over this extended period of waste emplacement operations, WIPP would remain a stable federal employer in the ROI economy, providing direct employment for 1,095 site personnel annually. Indirectly, the operation of WIPP as a waste emplacement facility (from 2010 through 2200) would annually support 2,443 jobs in the ROI work force.

Table 5-57
Economic Impacts within the WIPP ROI for Action Alternative 3

Economic Effects	Total Output of Goods and Services (in millions of 1994 dollars)	Total Employment (Full- and Part-Time Jobs)	Total Labor Income (in millions of 1994 dollars)	Carlsbad Output of Goods and Services (in millions of 1994 dollars)	Carlsbad Employment (Full- and Part-Time Jobs)	Carlsbad Labor Income (in millions of 1994 dollars)
Direct – Annual	113	1,095	52	95	979	46
Indirect & Induced – Annual	204	2,443	75	172	2,185	67
Total – Annual	317	3,538	126	267	3,164	113
Total - Operations (190 years)	60,230	672,220 [a]	23,940	50,730	601,160 [a]	21,470

[a] Job-years (number of annual jobs supported multiplied by the number of years in the project).

Because the projected average annual project budget would be close to historical levels, Action Alternative 3 would not be expected to result in additional use of government-provided goods or services (schools, police, fire protection, and health protection), nor require major capital investments in public infrastructure within the ROI. For this same reason Action Alternative 3 would not be expected to impact the local real estate market, nor result in major changes in WIPP ROI work force population.

5.4.8 Transportation

This section presents the transportation impacts for Action Alternative 3.

5.4.8.1 Route Characteristics and Shipment Projections

The methods used to estimate route characteristics and the number of shipments for Action Alternative 3 were the same as those presented in Section 5.1.8.1. Table 5-58 presents the number of shipments that would be required.

Table 5-58
Number of Truck Shipments to WIPP for Action Alternative 3 [a]

Waste Treatment Site	CH-TRU Waste			RH-TRU Waste		
	Basic Inventory	Additional Inventory	Total Inventory	Basic Inventory	Additional Inventory	Total Inventory
Hanford Site	24,531	8,600	33,131	60,789	3,076	63,865
Idaho National Engineering and Environmental Laboratory Argonne/National Laboratory-West	10,386	7,769	18,155	---	---	---
Los Alamos National Laboratory	7,628	1,907	9,535	---	---	---
Oak Ridge National Laboratory	---	---	---	7,050	3,691	10,741
Rocky Flats Environmental Technology Site	2,897	---	2,897	---	---	---
Savannah River Site	2,885	706	3,591	---	---	---
Total	48,327	18,982	67,309	67,839	6,767	74,606

[a] The total number of shipments presented here do not include shipments from the generator sites to the consolidation sites. The number of consolidation shipments are 535 for CH-TRU waste and 8,254 for RH-TRU waste.

5.4.8.2 Accidents, Injuries, Fatalities, and Pollution-Related Health Effects from Truck Transportation

Table 5-59 presents a summary of the nonradiological impacts for Action Alternative 3. The fatalities due to the pollution-related health effects of diesel fuel and the impacts due to transporting the waste to treatment sites are also presented. The number of pollution-related fatalities was based upon the total miles traveled in urban areas and a conversion factor of 9.9×10^{-8} LCFs per kilometer (1.6×10^{-7} LCFs per mile) (Rao et al. 1982). For Action Alternative 3, the total number of accidents, injuries, and fatalities over the entire shipping campaign were estimated to be 239, 165, and 22, respectively. Details on the methods used are presented in Appendix E.

Table 5-59
Nonradiological Impacts of Transporting
TRU Waste by Truck for Action Alternative 3

Category	CH-TRU Waste			RH-TRU Waste			Total		
	Basic Inventory	Additional Inventory	Total Inventory	Basic Inventory	Additional Inventory	Total Inventory	Basic Inventory	Additional Inventory	Total Inventory
Number of Accidents	73	31	104	124	12	135	197	43	239
Number of Injuries	51	20	71	85	10	94	136	30	165
Number of Fatalities	7	3	10	11	1	12	18	4	22
Pollution Health Effects (fatalities)	0.2	0.09	0.3	0.4	0.05	0.4	0.6	0.1	0.7

5.4.8.3 Accident-Free Radiological Impacts from Truck Transportation

Accident-free radiological impacts occur during routine transportation and are the result of public and worker exposure to direct radiation at levels allowed by transportation regulations. The methods used to estimate accident-free radiological impacts for Action Alternative 3 were identical to those described for the Proposed Action.

Table 5-60 presents a summary of the accident-free radiological impacts for Action Alternative 3. It includes the impacts due to transporting waste to the treatment sites for treatment (see Appendix E). The total occupational and nonoccupational impacts were estimated to be 1 LCF and 14.5 LCFs, respectively.

Table 5-61 summarizes the radiological impacts to MEIs for accident-free shipments by truck under Action Alternative 3.

Table 5-60
Aggregate Accident-Free Population Radiological Impacts from Truck Transportation for Action Alternative 3 (LCFs) [a]

Exposure Category	CH-TRU Waste			RH-TRU Waste			Total		
	Basic Inventory	Additional Inventory	Total Inventory	Basic Inventory	Additional Inventory	Total Inventory	Basic Inventory	Additional Inventory	Total Inventory
Occupational	0.5	0.2	0.7	0.3	0.04	0.4	0.8	0.2	1.0
Nonoccupational									
Stops	3.3	1.4	4.7	7.8	.9	8.7	11.1	2.3	13.4
Sharing Route	0.2	0.08	0.3	0.4	0.05	0.5	0.6	0.1	0.8
Along Route	0.07	0.03	0.1	0.2	0.03	0.2	0.3	0.06	0.3
Nonoccupational - Total	3.6	1.5	5.1	8.4	1.0	9.4	12.0	2.5	14.5

[a] Exposure during stops is based upon 50 individuals exposed at 20 meters. Stop time, in hours, is based upon 0.011d where d is the distance traveled in kilometers. These parameters are built into the RADTRAN code but substantially overestimate exposures from WIPP shipments. Because WIPP shipments would use two-driver teams (eliminating the need for overnight stops to sleep) and because the shipments would stop at sites chosen, in part, for their lack of population, the actual impacts from stops would be much lower.

Table 5-61
Radiological Impacts to MEIs from Truck Transportation for Action Alternative 3 (Probability of an LCF)

Individual	CH-TRU Waste	RH-TRU Waste	Total
Stuck in traffic next to shipment	2.5E-6	5.0E-6	7.5E-6
Departure Inspector	1.0E-3	6.0E-3	7.0E-3
State Vehicle Inspector	2.1E-3	7.8E-3	9.9E-3
Residing adjacent to access route	2.0E-4	6.0E-4	8.0E-4
Rest stop employee	1.0E-4	3.0E-4	4.0E-4

5.4.8.4 Radiological Impacts from Truck Transportation Accidents

Two types of analyses were conducted for SEIS-II radiological impacts due to traffic accidents. The first analysis determined the radiological impacts due to accidents occurring from each of the principal treatment sites to WIPP. The results for route-specific accidents summed over the entire shipping campaign are presented in Table 5-62.

The second analysis assessed four bounding accident scenarios, two involving the breach of a TRUPACT-II and the other two involving the breach of an RH-72B cask. These assessments were to estimate the maximum potential impacts posed by a severe transportation accident. Details on the methods used to estimate impacts from bounding case accidents are presented in Section 5.1.8.4 and Appendix E.

Table 5-62
Aggregate Radiological Population Impacts
for Truck Transportation Accidents for Action Alternative 3 (LCFs)

Originating Site	CH-TRU Waste			RH-TRU Waste			Total		
	Basic Inventory	Additional Inventory	Total Inventory	Basic Inventory	Additional Inventory	Total Inventory	Basic Inventory	Additional Inventory	Total Inventory
Argonne National Laboratory-East	---	---	---	---	---	---	---	---	---
Hanford Site	0.6	0.2	0.8	0.08	4.0E-3	0.09	0.7	0.2	0.9
Idaho National Engineering and Environmental Laboratory/ANL-W	0.1	0.1	0.2	3.0E-3	5.0E-4	3.5E-3	0.1	0.1	0.2
Lawrence Livermore National Laboratory	---	---	---	---	---	---	---	---	---
Los Alamos National Laboratory	5.0E-3	1.5E-3	6.5E-3	2.0E-5	1.0E-5	3.0E-5	5.0E-3	1.5E-3	6.5E-3
Oak Ridge National Laboratory	---	---	---	5.0E-3	3.0E-3	8.0E-3	5.0E-3	3.0E-3	8.0E-3
Rocky Flats Environmental Technology Site	0.01	---	0.01	---	---	---	0.01	- - -	0.01
Savannah River Site	0.03	7.5E-3	0.04	---	---	---	0.03	7.5E-3	0.04
Total LCFs							**0.9**	**0.3**	**1.2**

For Action Alternative 3, the potential radiological releases from the bounding case accidents were assumed to be the same as those presented under the Proposed Action (a maximum of 16 LCFs to the population and 0.06 probability of cancer to the maximally exposed individual.) The shred and grout treatment process used for treating TRU waste under Action Alternative 3 would reduce the void space in the drums, but increase the waste volume by approximately 20 percent. It was assumed that the release fraction for waste treated using a shred and grout process would be the same as for waste treated under the Proposed Action. The bounding accident consequences therefore, are assumed to be the same as those for the Proposed Action (see Section 5.1.8.4).

5.4.8.5 Hazardous Chemical Impacts from Severe Truck Transportation Accidents

Exposures to hazardous chemical releases from a severe accident would present a negligible hazard to the exposed population under Action Alternative 3. Although the TRU waste for Action Alternative 3 would be treated using a shred and grout process and the inventory for Action Alternative 3 is larger than that for the Proposed Action, the bounding concentrations of VOCs and metals in the TRUPACT-II or RH-72B cask and the release fractions in an accident were estimated to be the same, and so potential impacts would be the same as for the Proposed Action.

5.4.8.6 Impacts from Rail Transportation

This section presents a summary of transportation impacts for both regular and dedicated rail transportation. These impacts were determined by scaling the transportation impacts for truck shipments to estimate the impacts for rail. In Section 5.2.8.6 and Appendix E, the impact parameters are identified, and the differences between truck and rail transportation are explained. Table 5-63 presents the rail impacts under Action Alternative 3.

Table 5-63
Impacts from Rail Transportation
for Action Alternative 3

Aggregate Traffic Related Fatalities	
Regular Rail	11
Dedicated Rail	154
Aggregate Accident-Free Radiological Impacts (LCFs)	
CH-TRU Waste	
Occupational Exposure	0.03
Nonoccupational	
Stops	0.6
Sharing Route	2.6E-3
Along Route	0.1
Nonoccupational Exposure - Total	0.7
RH-TRU Waste	
Occupational Exposure	0.02
Nonoccupational	
Stops	1.1
Sharing Route	4.9E-3
Along Route	0.3
Nonoccupational Exposure - Total	1.3
Total CH-TRU and RH-TRU Waste	
Occupational Exposure	0.05
Nonoccupational	
Stops	1.6
Sharing Route	7.5E-3
Along Route	0.4
Nonoccupational Exposure - Total	2.0
Aggregate Radiological Impacts from Rail Transportation Accidents (LCFs)	
CH-TRU Waste	1.1
RH-TRU Waste	0.1
Total CH-TRU and RH-TRU Waste	1.2

The bounding case accident analyses for rail transportation were based on assumptions presented in Section 5.2.8.6. Though the waste would be treated by a shred and grout process, the impacts would be similar to those presented for the Action Alternative 1 rail accident analyses. The greatest impacts were found for the two accidents in which conservative inventories were assumed, 32 LCFs to the exposed population and a 0.12 probability of a cancer fatality for the maximally exposed individual.

5.4.9 Human Health Impacts from Waste Treatment, Storage, and Disposal Operations

This section presents human health impacts to the public, noninvolved workers, and involved workers from waste treatment, lag storage, and WIPP disposal operations under Action Alternative 3. As for other action alternatives, impacts from waste treatment were adjusted from those presented in the WM PEIS; a description of the adjustments is provided in Appendix B.

Impacts from lag storage at the treatment sites and WIPP disposal operations were estimated using the general methods and assumptions used for the human health analyses of Proposed Action and Action Alternative 1. Action Alternative 3 includes the Total Inventory (except for PCB-commingled waste). PCB-commingled TRU waste is known to exist at three sites: 242 cubic meters (8,550 cubic feet) at Hanford, 461 cubic meters (16,300 cubic feet) at INEEL, and 19 cubic meters (670 cubic feet) at Mound.

The major distinction of this alternative for human health analyses is the shred and grout treatment method. Shred and grout treatment of waste reduces gas generation and changes the quantity of

VOCs emitted from the waste containers; it also results in a net waste volume increase of about 20 percent overall. The increase in volume would reduce the concentration of the radionuclides in the waste, which decreases the estimated average container dose rates. Denser waste matrices, such as grout, tend to decrease surface dose rates because of more self-absorption of the external radiation emitted by radionuclides in the waste. Worker radiological impacts reflect the impact of these factors. Appendix F provides additional information on the methods used to determine the impacts from lag storage and WIPP disposal operations.

5.4.9.1 Public

Impacts to the populations and to the MEIs under Action Alternative 3 are presented in this section; results are presented in Table 5-64. Impacts from waste treatment, lag storage, and WIPP disposal operations are presented separately because different populations and individuals would be impacted by these activities. Waste treatment and lag storage would take place at six DOE sites; none of them WIPP. Waste disposal operations would take place only at WIPP. Population impacts were estimated for those members of the public residing within 80 kilometers (50 miles) of all treatment sites, all lag storage sites, and at WIPP. The impacts to the MEIs from waste treatment and lag storage are presented for the highest individual waste treatment sites; the MEI from disposal operations is near the WIPP site. See Chapter 3 for additional information on where treatment and storage would occur under Action Alternative 3.

Table 5-64
Lifetime Human Health Impacts to the Public from Waste Treatment, Lag Storage, and WIPP Disposal Operations for Action Alternative 3

Category	Waste Treatment Impacts		Lag Storage Impacts		WIPP Disposal Operations Impacts	
	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence) [b]
MEI [c, d]						
Basic Inventory						
CH-TRU Waste	2E-7 (L)	4E-13 (L)	2E-7 (L)	1E-7 (L)	2E-7	5E-9
RH-TRU Waste	7E-12 (O)	1E-11 (O)	1E-9 (O)	4E-8 (H)	7E-10	9E-10
Total Waste	2E-7 (L)	1E-11 (O)	2E-7 (L)	1E-7 (L)	2E-7	6E-9
Total Inventory						
CH-TRU Waste	4E-7 (L)	7E-13 (I)	3E-7 (L)	2E-7 (L, H)	3E-7	1E-8
RH-TRU Waste	1E-11 (O)	2E-11 (O)	2E-9 (O)	4E-8 (H)	8E-10	9E-10
Total Waste	4E-7 (L)	2E-11 (O)	3E-7 (L)	3E-7 (H)	3E-7	1E-8
Population [b]						
Basic Inventory						
CH-TRU Waste	3E-3	5E-9	1E-3	2E-3	1E-4	5E-6
RH-TRU Waste	3E-7	3E-7	3E-5	2E-4	9E-7	5E-7
Total Waste	3E-3	3E-7	1E-3	2E-3	1E-4	6E-6
Total Inventory						
CH-TRU Waste	4E-3	1E-8	2E-3	2E-3	2E-4	1E-5
RH-TRU Waste	4E-7	4E-7	5E-5	2E-4	1E-6	5E-7
Total Waste	4E-3	4E-7	2E-3	2E-3	2E-4	1E-5
Aggregate Total	4E-3	4E-7	3E-3	4E-3	3E-4	2E-5

[a] The probability of an LCF to the MEI, and the number of LCFs in the population
[b] If a panel full of CH-TRU waste remained open during the entire 70-year lifetime of the MEI and VOCs were emitted at a constant rate, the MEI lifetime risk from the CH-TRU waste would be 2E-8.
[c] I = INEEL, L = LANL, H = Hanford, O = ORNL.
[d] The workers considered for treatment impacts, lag storage impacts, and operations impacts are different.

Note: Sites in parentheses indicate where the greatest MEI impact would occur.

Waste Treatment

No LCFs (4×10^{-3} LCF) or cancer incidence (4×10^{-7} cancers) would be expected in the total population around the waste treatment sites. The MEI would be at LANL for radiological impacts (4×10^{-7} probability of an LCF), and impacts at all sites would not exceed a 2×10^{-11} probability of a cancer incidence. The maximum HI for the MEI would be 7×10^{-10}.

Lag Storage

No LCFs would be expected in the total population around the lag storage sites (2×10^{-3} LCFs); no cancer incidence (2×10^{-3} cancers) would be expected in the total population from hazardous chemical exposure. The MEI would be at LANL for radiological impacts (3×10^{-7} probability of an LCF) and at Hanford for hazardous chemical impacts (also 3×10^{-7} probability of a cancer incidence). No noncarcinogenic health effects would occur because the maximum HI for any MEI would be 9×10^{-4}.

The aggregate total indicated in Table 5-64 refers to the impacts expected over the entire operational period under Action Alternative 3. Lag storage impact estimates conservatively assume that the lag storage period is equivalent to the disposal operations period, which is estimated to be 57 years for CH-TRU waste and 190 years for RH-TRU waste. No LCFs (3×10^{-3} LCFs) or cancer incidence (4×10^{-3} cancers) would be expected over the several generations that would be exposed to the small potential routine releases of radioactive or hazardous materials.

WIPP Disposal Operations

No LCFs would be expected in the population around WIPP from radiation exposure (2×10^{-4} LCF). No cancer incidence (1×10^{-5} cancers) would be expected in the population from hazardous chemical exposure.

The MEI was assumed to be located at the Land Withdrawal Area boundary, the closest point at which an individual could reside. The MEI would have a 3×10^{-7} probability of an LCF from radiation exposure and a 1×10^{-8} probability of a cancer incidence from hazardous chemical exposure. No noncarcinogenic health effects would occur; the maximum HI for the MEI would be 1×10^{-4}.

The aggregate total indicated in Table 5-64 refers to the impacts expected over the entire operational period. The operational period for the disposal of the Total Inventory is expected to be 57 years for CH-TRU waste and 190 years for RH-TRU waste. No LCFs (3×10^{-4} LCFs) or cancer incidence (2×10^{-5} cancers) would be expected over the several generations of exposure to the estimated releases.

5.4.9.2 Noninvolved Workers

Impacts to the noninvolved worker population and the maximally exposed noninvolved worker under Action Alternative 3 are presented in this section; results are presented in Table 5-65. A noninvolved worker is an employee who works at a site but is not directly involved in the treatment, storage, handling, or disposal of waste. Impacts from waste treatment, lag storage, and WIPP disposal operations are presented separately because different noninvolved worker populations and individuals would be impacted by these activities. Waste treatment and lag storage

Table 5-65
Lifetime Human Health Impacts to Noninvolved Workers from Waste Treatment, Lag Storage, and WIPP Disposal Operations for Action Alternative 3

Category	Waste Treatment Impacts		Lag Storage Impacts		WIPP Disposal Operations Impacts	
	Radiological (LCF) [a]	Hazardous Chemicals (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemicals (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemicals (Cancer Incidence)
Maximally Exposed Noninvolved Worker [b, c]						
Basic Inventory						
CH-TRU Waste	1E-7 (L)	2E-12 (I)	8E-7 (S)	2E-7 (H)	2E-7	3E-8
RH-TRU Waste	6E-12 (O)	9E-11 (O)	1E-8 (O)	8E-8 (H)	2E-9	2E-9
Total Waste	1E-7 (L)	9E-11 (O)	8E-7 (S)	3E-7 (H)	2E-7	3E-8
Total Inventory						
CH-TRU Waste	2E-7 (L)	6E-12 (I)	2E-6 (S)	3E-7 (H)	3E-7	5E-8
RH-TRU Waste	9E-12 (O)	1E-10 (O)	2E-8 (O)	9E-8 (H)	2E-9	2E-9
Total Waste	2E-7 (L)	1E-10 (O)	2E-6 (S)	4E-7 (H)	3E-7	5E-8
Population [c]						
Basic Inventory						
CH-TRU Waste	5E-4	4E-9	0.02	4E-3	2E-4	3E-5
RH-TRU Waste	9E-9	9E-8	2E-4	1E-3	2E-6	2E-6
Total Waste	5E-4	1E-7	0.02	5E-3	2E-4	3E-5
Total Inventory						
CH-TRU Waste	7E-4	9E-9	0.04	8E-3	3E-4	5E-5
RH-TRU Waste	1E-8	1E-7	2E-4	1E-3	2E-6	2E-6
Total Waste	7E-4	1E-7	0.04	9E-3	3E-4	5E-5
Aggregate Total	7E-4	1E-7	0.07	0.02	5E-4	9E-5

[a] The probability of an LCF occurring to the maximally exposed noninvolved worker, and the number of LCFs in the population.
[b] L = LANL, H = Hanford, I = INEEL, O = ORNL, S = SRS
[c] The workers considered for treatment impacts, lag storage impacts, and operations impacts are different.

Note: Sites in parentheses indicate where the greatest MEI impact would occur.

would take place at six DOE sites not including WIPP, while disposal operations would take place only at WIPP. Noninvolved worker population impacts were estimated as the total for all treatment sites, for all lag storage facilities, and at WIPP. The impacts to the maximally exposed noninvolved worker from waste treatment and lag storage are presented for the highest individual waste treatment sites. The maximally exposed noninvolved worker from disposal operations was assumed to work continuously at the WIPP location where emissions have the least atmospheric dispersion and thus the greatest potential impact. This location was 200 meters (660 feet) east of the exhaust filter building. The maximum ground-level concentrations of any airborne contamination would be expected at this location.

Waste Treatment

Under Action Alternative 3, radiological impacts to the noninvolved workers from waste treatment would be somewhat greater than nonradiological impacts. No LCFs (7×10^{-4} LCFs) or cancer incidence (2×10^{-7} cancers) would be expected in the total noninvolved worker population at the waste treatment sites. The maximally exposed noninvolved worker would be at LANL for radiological impacts (2×10^{-7} probability of an LCF) and at ORNL for hazardous chemical impacts

(1×10^{-10} probability of a cancer incidence). No noncarcinogenic health effects are predicted. The maximum HI for the maximally exposed noninvolved worker would be 8×10^{-9}, and no health effect is predicted unless the HI is 1 or higher.

Lag Storage

No LCFs would be expected in the total noninvolved worker population at the lag storage sites (4×10^{-2} LCF); no cancer incidence (9×10^{-3} cancers) would be expected in the total noninvolved worker population from hazardous chemical exposure. The maximally exposed noninvolved worker would be at SRS for radiological impacts (2×10^{-6} probability of an LCF) and at Hanford for hazardous chemical impacts (4×10^{-7} probability of a cancer incidence). No noncarcinogenic health effects would occur; the maximum HI for the maximally exposed noninvolved worker would be 4×10^{-3}.

The aggregate total indicated in Table 5-65 refers to the impacts to the noninvolved worker population at the lag storage sites expected over the entire operational period under Action Alternative 3. Lag storage impact estimates conservatively assume that the lag storage period is equivalent to the disposal operations period, which is estimated to be 57 years for CH-TRU waste and 190 years for RH-TRU waste. No LCFs (0.07 LCFs) or cancer incidence (0.02 cancers) would be expected in the several generations that would be exposed to the small potential routine releases of radioactive or hazardous materials under incident-free operations.

WIPP Disposal Operations

No LCFs would be expected in the WIPP noninvolved worker population from radiation exposure (3×10^{-4} LCF). VOC release estimates were the same as for the public. No cancer incidence (5×10^{-5} cancers) would be expected in the noninvolved worker population from hazardous chemical exposure. All 1,095 WIPP employees were assumed to be exposed at the same level as the maximally exposed noninvolved worker.

The maximally exposed noninvolved worker would have a 3×10^{-7} probability of an LCF from radiation exposure and a 5×10^{-8} probability of a cancer incidence from hazardous chemical exposure. No noncarcinogenic health effects would occur; the maximum HI for the maximally exposed noninvolved worker would be 1×10^{-3}.

The aggregate total indicated in Table 5-65 shows that no LCFs (5×10^{-4} LCFs) or cancer incidence (9×10^{-5} cancers) would be expected to the noninvolved workers at the WIPP site during the entire disposal operations period under Action Alternative 3.

5.4.9.3 Involved Workers

Impacts to involved workers who would handle waste during treatment, lag storage, and WIPP disposal operations under Action Alternative 3 are presented in this section. Results are presented in Table 5-66, and additional information is presented in Appendix F and Appendix B for waste treatment impacts. All worker exposures to radiation and hazardous chemicals would be controlled to ALARA levels. Administrative controls such as worker and area monitoring, rotation of workers to reduce exposures, and standard operating procedures would be used to limit exposures.

Table 5-66
Lifetime Human Health Impacts to Involved Workers from Waste Treatment, Lag Storage, and WIPP Disposal Operations for Action Alternative 3 [a]

	Waste Treatment Impacts		Lag Storage Impacts		WIPP Disposal Operations Impacts	
Category	Radiological (LCF)	Hazardous Chemicals (Cancer Incidence)	Radiological (LCF)	Hazardous Chemicals (Cancer Incidence)	Radiological (LCF)	Hazardous Chemicals (Cancer Incidence)
Population					(36 workers)	(36 workers)
Basic Inventory						
CH-TRU Waste	0.7	1E-5	0.2	0.03	0.05	4E-3
RH-TRU Waste	9E-3	6E-6	≤0.2	≤0.03	≤0.05	4E-4
Total Waste	0.7	2E-5	≤0.4	≤0.06	≤0.1	≤4E-3
Total Inventory						
CH-TRU Waste	1.5	3E-5	0.3	0.06	0.1	7E-3
RH-TRU Waste	0.01	9E-6	≤0.3	≤0.06	≤ 0.1	4E-4
Total Waste	1.5	4E-5	≤0.6	≤0.1	≤ 0.2	≤7E-3
Aggregate Total	1.5	4E-5	0.6	≤0.4	0.3	≤0.01

[a] The workers considered for treatment impacts, lag storage impacts, and operations impacts are different.

Waste Treatment

A maximum of 1.5 radiation-related LCFs could occur in the involved worker population, while no cancer incidence (4×10^{-5} cancers) would be expected from hazardous chemical exposure. No noncarcinogenic health effects are predicted. The maximum exposure index for a waste treatment worker would be 3×10^{-4}, and no health effect is predicted unless the HI is 1 or higher.

Lag Storage

Assuming 35 years of management of the entire inventory, radiological impacts to the lag storage involved worker population would be less than 0.6 LCF, and hazardous chemical impacts would be less than 0.1 cancers. No noncarcinogenic health effects would occur. Involved worker lag storage impacts would be larger from CH-TRU waste storage operations than from RH-TRU waste storage operations. Impacts from RH-TRU waste lag storage operations would be less because of remote RH-TRU waste handling and greater administrative controls for RH-TRU waste. No specific RH-TRU lag storage impact estimates were made because specific RH-TRU waste handling configurations and procedures are unknown. RH-TRU waste lag storage impacts would be assessed in greater detail in future site-wide or project-specific NEPA reviews.

The impacts from CH-TRU waste would be from the external radiation dose received during waste container handling. Potential radiological impacts from inhalation of radioactive gases released from waste containers would be negligible. Involved worker impacts from lag storage were calculated by assuming waste handlers would spend 2 hours every workday at 1 meter (3.3 feet) from the CH-TRU waste containers and were assumed to be exposed over a 35-year career. Container dose rates were decay-corrected over 35 years, and 20 percent of the Total Inventory was assumed to be monitored annually.

The aggregate total indicated in Table 5-66 refers to the impacts to the involved worker population at the lag storage sites over the entire operational period under Action Alternative 3. Lag storage impact estimates conservatively assume that the lag storage period is equivalent to the disposal operations period, which is estimated to be 57 years for CH-TRU waste and 190 years for RH-TRU waste. A maximum of 0.6 LCFs and less than 0.4 cancers would be expected over the several generations of involved workers that would be exposed externally or via inhalation of hazardous chemicals during lag storage operations. The radiological impact estimates reflect the aggregate impacts analyses presented in detail in Appendix F. The hazardous chemical impacts were estimated in the same manner as the public and noninvolved worker estimates.

WIPP Disposal Operations

Radiological impacts to the involved worker population at WIPP from disposal operations would be less than 0.2 LCF. WIPP involved worker radiological impacts would be from external radiation dose, and it was assumed that each involved worker who handled CH-TRU waste for 400 hours per year. The operational period was determined by assuming that 2.5 years of disposal operations were required to fill each panel. Impacts to involved workers from RH-TRU waste handling were assumed to be the same or less than those from CH-TRU waste handling. This assumption is conservative because RH-TRU waste is typically handled using remote-handling equipment, workers are usually protected by radiation shielding, and stricter administrative procedures are used. The impact from handling RH-TRU waste, therefore, would probably be less than the impact from handling CH-TRU waste.

Hazardous chemical carcinogenic impacts to the involved worker population would be less than 7×10^{-3} cancers. Involved worker exposures to VOCs were evaluated for workers in the Waste Handling Building and underground. The potential carcinogenic impacts would be greatest for the individual underground worker. Noncarcinogenic health effects were also estimated for WIPP workers who would handle waste. The same methods were used as for the Proposed Action (Section 5.1.9.3).

No hazardous chemical noncarcinogenic health effects would occur. The initial maximum HI estimates for involved workers were from carbon tetrachloride, with values of 2 and 10, respectively, for workers in the Waste Handling Building and the underground. Further evaluation was conducted by comparing the worker exposure air concentration to the PEL for carbon tetrachloride. The worker air concentrations would be, at a minimum, two orders of magnitude below the PEL, so no noncarcinogenic health effects would occur. Workers were assumed to be exposed for a working lifetime of 35 years.

The aggregate total indicated in Table 5-66 refers to the impacts to the involved worker population at WIPP over the entire disposal operations period under Action Alternative 3. No LCFs (0.3 LCFs) or cancer incidence (less than 0.01 cancers) would be expected over the several generations of involved workers at WIPP. Total radiological impacts would be approximately twice the number of impacts estimated for the individual during the first 35 years of CH-TRU waste disposal operations at WIPP. Radiological decay would reduce the radiological impacts to each generation of WIPP workers. Hazardous chemical impacts were conservatively estimated by assuming continuous exposure to the same releases over the entire disposal operations period.

5.4.10 Facility Accidents

This section describes potential consequences of facility accidents at the treatment sites from the shred and grout treatment of waste, at the treatment sites from waste storage after treatment but before shipment to WIPP, and at WIPP during waste management and disposal operations. Consequences of treatment and storage accidents were evaluated at the six treatment sites (Hanford, LANL, INEEL, SRS, RFETS, and ORNL) that would handle all of the CH-TRU and RH-TRU waste under Action Alternative 3.

Inhalation is the dominant exposure pathway for accidental releases of radionuclides and hazardous chemicals. Radiological consequences are potentially much greater for members of the public and the noninvolved workers than hazardous chemical consequences and are dominated by inhalation of transuranic radionuclides. Details of the methods and assumptions used and complete accident descriptions are provided in Appendix G.

5.4.10.1 Waste Treatment Accidents

Three potential waste treatment accidents were evaluated under Action Alternative 3; they are presented in Table 5-67. Results are presented only for accidents involving CH-TRU waste. They would be greater than similar accidents involving RH-TRU waste. Treatment accidents analyzed include a high-frequency/low-consequence operational accident which is expected to be applicable under any facility design, a low-frequency/high-consequence operational accident, and a beyond-design-basis natural disaster accident. For the purposes of analyses, an earthquake was assumed to be the initiating event the beyond-design-basis accident for analysis (rather than a plane crash or tornado, for instance). Accident analysis information is presented in Appendix G.

Table 5-67
Treatment Accident Scenarios Evaluated for Action Alternative 3

Accident Scenarios	Annual Occurrence Frequency	Description
Waste Spill (Accident Scenario T7)	0.01	Wet grout is spilled onto facility floor before it is placed in a drum.
Fire (Accident Scenario T8)	1E-4	Pyrophoric material inside a shredder causes shredder contents to burn.
Earthquake (Accident Scenario T9)	1E-5 or less	A beyond-design-basis earthquake (or other natural event) collapses the roof, causing drums to rupture and HEPA filters to fail.

Estimated radiological consequences are presented as the number of LCFs in the exposed population and the probability of an LCF occurring in MEIs (in tables the probability of an LCF is presented for MEIs). Carcinogenic and noncarcinogenic consequences from hazardous chemicals, both VOCs and heavy metals, were estimated. Carcinogenic consequences are presented as the number of cancers in the exposed population and the probability of cancer for MEIs. Noncarcinogenic consequences from exposure to VOCs and heavy metals were estimated by two different methods: IDLH-equivalent ratios and ERPG ratios.

In general, potential radiological consequences would be higher than hazardous chemical consequences, which are very small for most accident cases. Estimated results for members of the

Table 5-68
Radiological Consequences of Treatment Accidents for Action Alternative 3 [a]

Accident Scenarios		Population (Number of LCFs)	MEI (probability of an LCF)	Maximally Exposed Noninvolved Worker (probability of an LCF)
CH-TRU Waste	Waste Spill (Accident Scenario T7)	Maximum: 1E-4 (RFETS)	Maximum: 6E-8 (LANL)	Maximum: 2E-7 (Hanford)
	Fire (Accident Scenario T8)	Maximum: 6E-3 (RFETS)	Maximum: 3E-6 (LANL)	Maximum: 8E-6 (Hanford)
	Earthquake (Accident Scenario T9)	Hanford: 6 INEEL: 0.3 LANL: 2 RFETS: 6 SRS: 0.5	Hanford: 3E-3 INEEL: 2E-4 LANL: 5E-3 RFETS: 4E-4 SRS: 6E-5	Hanford: 0.02 INEEL: 0.02 LANL: 0.02 RFETS: 0.01 SRS: 0.01
RH-TRU Waste	Waste Spill (Accident Scenario T7)	Maximum: 5E-9 (ORNL)	Maximum: 4E-12 (ORNL)	Maximum: 4E-12 (ORNL)
	Fire (Accident Scenario T8)	Maximum: 3E-7 (ORNL)	Maximum: 2E-10 (ORNL)	Maximum: 2E-10 (ORNL)
	Earthquake (Accident Scenario T9)	Hanford: 1E-4 ORNL: 3E-4	Hanford: 7E-8 ORNL: 3E-7	Hanford: 4E-7 ORNL: 7E-7

[a] The site with the greatest consequence is shown in parentheses.

Note: This table presents estimates of the consequences of accident scenarios and does not reflect the frequency (or probability) of the accident occurring.

public, the maximally exposed noninvolved worker, and the maximally exposed involved worker are presented below and in Table 5-68. Consequences to the maximally exposed involved worker were addressed qualitatively.

Public

Population consequences from treatment accidents were estimated for the exposed populations around the six treatment sites. Potential consequences to the population and MEIs at the five sites vary over a wide range because population distributions, distances to MEIs, and atmospheric dispersion factors differ among sites. No LCFs would be expected in the exposed population from the waste spill accident or fire in a waste shredder accident (Accident Scenario T7 and T8). Up to 6 LCFs were estimated to occur from the earthquake (Accident Scenario T9) at RFETS and Hanford. The radiological consequences were estimated to be the highest to the MEI at LANL for all three accidents. Consequences due to the earthquake (Accident Scenario T9) were estimated to range from a 6×10^{-5} (at SRS) to 5×10^{-3} (at LANL) probability of an LCF to the MEI.

Carcinogenic consequences from VOCs would be one to five orders of magnitude greater than consequences from heavy metals for the waste spill and earthquake accidents (Accident Scenarios T7 and T9, respectively). Heavy metals would account for all carcinogenic consequences from the fire accident (Accident Scenario T8) because VOCs would be consumed by the fire. No cancers were estimated to occur in the exposed population from the hazardous chemical releases of any accident. The maximum probability of cancer to the MEI would be 6×10^{-9} from any of the three treatment accidents. The ORNL, Hanford, LANL, and RFETS MEIs could all develop irreversible or severe noncarcinogenic health effects from exposure to hazardous chemicals as a result of the earthquake.

Maximally Exposed Noninvolved Worker

The maximally exposed noninvolved worker was assumed to be at the location of greatest consequence outside of the waste treatment building. The consequences to the noninvolved worker were estimated to not vary significantly across the five sites. Radiological consequences to the

maximally exposed noninvolved worker would result in a 2×10^{-7} probability of an LCF from the waste spill accident (Accident Scenario T7 at Hanford), 8×10^{-6} probability of an LCF from the fire accident (Accident Scenario T8 at Hanford), and up to 0.02 probability of an LCF (at Hanford, INEEL, and LANL) from the beyond-design-basis earthquake (Accident Scenario T9).

No cancer incidents would be expected from the release of hazardous chemicals or metals from any of the accidents; the greatest probability of cancer would be 2×10^{-8}. Under the earthquake scenario (Accident Scenario T9), the maximally exposed noninvolved worker at all the sites would have a chance of developing irreversible or severe noncarcinogenic health effects, and could develop life threatening effects. These effects would be because of exposures to heavy metals and VOCs.

Maximally Exposed Involved Worker

No consequences to the maximally exposed involved worker would be anticipated from either the waste spill or fire accidents (Accident Scenarios T7 or T8, respectively). These accidents are such that involved workers would be able to evacuate immediately or would not be affected by the event. Substantial consequences would be possible due to the events of the earthquake scenario (Accident Scenario T9), ranging from workers killed by debris from collapsing treatment facilities to high external radiation doses from RH-TRU waste being treated. Intakes of radionuclides, VOCs, and heavy metals would also occur.

5.4.10.2 Waste Storage Accidents

Three potential waste storage accidents were evaluated for Action Alternative 3; they are presented in Table 5-69. CH-TRU waste would be consolidated at five sites for lag storage under Action Alternative 3. The potential accident consequences at the five sites were evaluated in detail; the sites would be Hanford, INEEL, LANL, RFETS, and SRS. A sixth site, ORNL, would store only for RH-TRU waste under Action Alternative 3. Only CH-TRU accident consequences are presented in this section; the consequences of an RH-TRU storage facility failure in the event of an earthquake are presented in detail in Appendix G.

Table 5-69
Storage Accident Scenarios Evaluated for Action Alternative 3

Accident Scenarios	Annual Occurrence Frequency	Description
Drum Puncture, Drop and Lid Failure (Accident Scenario S1) [a]	1E-2 to 1E-4	A forklift strikes and punctures a drum on a lower level of a stack in the storage facility. The stack is destablilized and two drums fall to the ground and lose their lids upon impact.
Drum Fire (Accident Scenario S2) [a]	1E-4 to 1E-6	A fire spontaneously erupts in a waste drum.
Earthquake (Accident Scenario S3)	1E- 5 or less	A beyond-design-basis earthquake (or other natural event) occurs, causing the collapse of the storage buildings.

[a] Occurrence frequencies for Accident Scenarios S1 and S2 were taken from reference documents applicable to waste packaged to meet the planning-basis WAC. The same range of frequencies were assumed to apply to grouted waste. In reality, the frequency of occurrence of Accident Scenario S2 would probably be substantially lower for the grouted waste than for the waste treated to planning-basis WAC.

Storage accidents analyzed include a high-frequency/low-consequence operational accident which is expected to be applicable under any facility design, a low-frequency/high-consequence operational accident, and a beyond-design-basis natural disaster accident (an earthquake). For Accident Scenarios S1 and S2, CH-TRU waste involved in the accidents was assumed to have the maximum radionuclide content allowable under the planning-basis WAC (80 PE-Ci per drum), conservative concentrations of VOCs (based on CH-TRU sampling and WAC limits), and conservative concentrations of heavy metals. Accident Scenario 3 involves a large number of waste containers; therefore, average site-specific drum PE-Ci values and average hazardous chemical concentrations were used in the analyses. Additional details on the accident analyses are presented in Appendix G.

Estimated radiological consequences are presented as the number of LCFs in the exposed population and the probability of an LCF occurring in MEIs. Carcinogenic and noncarcinogenic consequences from hazardous chemicals, both VOCs and heavy metals, were estimated. Carcinogenic consequences are presented as the number of cancers in the exposed population and the probability of cancer for MEIs. Noncarcinogenic consequences from exposure to VOCs and heavy metals were estimated by two different methods for the drum puncture and drum fire scenarios (Accident Scenarios S1 and S2, respectively): IDLH-equivalent ratios and ERPG ratios. Only IDLH-equivalent ratios were calculated for the catastrophic storage facility failure due to the earthquake (Accident Scenario S3). The potential noncarcinogenic consequences identified by ERPG ratios would be of minor importance during such a catastrophic event and its consequent site-operations upheaval.

In general, potential radiological consequences would be higher than hazardous chemical consequences, which are very small for most accident cases. Estimated results for members of the public, the maximally exposed noninvolved worker, and the maximally exposed involved worker are presented below and in Table 5-70.

Public

Population consequences from storage accidents were estimated for the exposed populations around the five CH-TRU waste treatment sites. Potential consequences to the population and MEIs at the five sites vary over a wide range because the population distributions, distances to MEIs, and

Table 5-70
Radiological Consequences of Storage Accidents for Action Alternative 3 [a]

Accident Scenarios	Population (number of LCFs)	MEI (probability of an LCF)	Maximally Exposed Noninvolved Worker (probability of an LCF)
Puncture and Lid Failure (Accident Scenario S1)	Maximum: 3E-5 (RFETS)	Maximum: 8E-9 (LANL)	Maximum: 2E-8 (Hanford, LANL)
Drum Fire (Accident Scenario S2)	Maximum: 5E-5 (RFETS)	Maximum: 2E-8 (LANL)	Maximum: 5E-8 (Hanford)
Earthquake (Accident Scenario S3)	Hanford: 9 INEEL: 0.3 LANL: 2 RFETS: 10 SRS: 2	Hanford: 5E-3 INEEL: 1E-4 LANL: 4E-3 RFETS: 6E-4 SRS: 2E-4	Hanford: 0.03 INEEL: 0.02 LANL: 0.02 RFETS: 0.02 SRS: 0.04

[a] The site with the greatest consequence is shown in parentheses.

Note: This table presents estimates of the consequences of accident scenarios and does not reflect the frequency (or probability) of the accident occurring.

atmospheric dispersion factors differ among sites. No LCFs would be expected in the exposed population due to the drum puncture or drum fire scenarios (Accident Scenarios S1 and S2, respectively), but LCFs were estimated to occur due to the earthquake scenario (Accident Scenario S3) at most sites. The consequences due to the earthquake ranged from 0.3 (at INEEL) to 10 (at RFETS) LCFs. The radiological consequences were estimated to be the highest to the MEI at LANL for the drum puncture and drum fire scenarios (Accident Scenarios S1 and S2). Consequences due to the earthquake scenario (Accident Scenario S3) were estimated to range from a 1×10^{-4} (at INEEL) to 5×10^{-3} probability of an LCF to the MEI.

Carcinogenic consequences from VOCs would be two to seven orders of magnitude greater than consequences from heavy metals for the drum puncture and earthquake accidents (Accident Scenarios S1 and S3, respectively). Heavy metals would account for all carcinogenic consequences from the drum fire (Accident Scenario S2) because VOCs would be consumed by the fire. No cancers were estimated to occur in the exposed population from the hazardous chemical releases of any accident. The maximum probability of cancer to the MEI would be 3×10^{-10} from the drum puncture or drum fire scenarios (Accident Scenarios S1 and S2). The maximum probability of cancer to the MEI would be 6×10^{-7} for the earthquake scenario (Accident Scenario S3 at Hanford). No noncarcinogenic consequences would be expected for any of the three accidents evaluated.

Maximally Exposed Noninvolved Worker

The maximally exposed noninvolved worker was assumed to be at the location of greatest consequence outside of the waste storage facility. The consequences to the noninvolved worker were estimated to vary over a narrow range. The range was narrow because of the uniform release height and close distances considered.

Radiological consequences to the maximally exposed noninvolved worker would result in a 2×10^{-8} probability of an LCF from the drum puncture scenario (Accident Scenario S1), 5×10^{-8} probability of an LCF from the events of the drum fire scenario (Accident Scenario S2), and up to a 0.04 probability of an LCF (at SRS) from the beyond-design-basis earthquake (Accident Scenario S3). Hazardous chemical consequences would be relatively minor in comparison to radiological consequences. The maximum probability of cancer to the maximally exposed noninvolved worker from VOC and heavy metal intakes would be 8×10^{-10} for the drum puncture and drum fire scenarios (Accident Scenarios S1 and S2). The corresponding consequence for the earthquake (Accident Scenario S3) would be 3×10^{-6} probability of cancer. No noncarcinogenic consequences to the noninvolved worker would be expected to result from the hazardous chemical releases for the accidents evaluated.

Maximally Exposed Involved Worker

The maximally exposed involved worker would be the individual most seriously affected by the events of the drum puncture scenario or earthquake (Accident Scenarios S1 and S3, respectively) because of close proximity to the accident. Consequences were quantitatively estimated for Accident S1 and qualitatively for Accident Scenarios S2 and S3. The worker could potentially have a 3×10^{-3} probability of an LCF as a result of the radionuclide intake during the events of the drum puncture scenario (Accident Scenario S1). The analysis assumed instantaneous radioactive material release from the three containers, expanding in a uniform hemisphere 5 meters (16 feet) in radius. The worker was assumed to inhale this air for 1 minute prior to exiting to a fresh air

source. The involved worker could have a 5 x 10^{-8} probability of contracting cancer from hazardous chemicals inhaled following the drum puncture (Accident Scenario S1). Noncarcinogenic consequences would include consequences to the maximally exposed involved worker from methylene chloride and would be irreversible, although not life-threatening.

Consequences due to the drum fire (Accident Scenario S2) would be serious if the worker happened to be adjacent to the drum when the fire began. However, a worker's actions are not required to initiate the accident; therefore, the probability of exposure of a worker adjacent to the fire is small. The smoke released from the drum would alert workers to the incident, and it, therefore, can be reasonably assumed that workers would avoid exposure to the smoke.

Catastrophic destruction of the storage facility during an earthquake (Accident Scenario S3) could result in death or serious injury to the maximally exposed involved worker.

5.4.10.3 WIPP Disposal Accidents

Eight potential accidents at WIPP during disposal operations were evaluated; they are presented in Table 5-71. Six of the accidents involve only CH-TRU waste (Accident Scenarios W1 through W5 and W7), one involves only RH-TRU waste (Accident Scenario W8), and one was evaluated for consequences from CH-TRU and RH-TRU waste (Accident Scenario W6). The drum fire accident (Accident Scenario W5) that was evaluated under the Proposed Action and Action Alternative 1 may not be relevant for the relatively noncombustible shred-and-grout waste matrix evaluated under Action Alternative 3. Accident consequences were nevertheless estimated, and the same annual occurrence frequency for the accident under the Proposed Action and Action Alternative 1 was conservatively applied. Annual occurrence frequencies are the same in all cases as those indicated for the Proposed Action and Action Alternative 1.

Table 5-71
WIPP Disposal Accident Scenarios for Action Alternative 3

Accident Scenarios	Annual Occurrence Frequency	Description
Drop, Lid Failure in Waste Handling Building (Accident Scenario W1)	0.01	A package of drums is dropped in the Waste Handling Building, a drum on top of the package falls and its lid seal fails.
Drop, Puncture Lid Failure in the Waste Handling Building (Accident Scenario W2)	0.01	Forklift strikes and punctures drums on lower level of stack in the Waste Handling Building. A drum on the upper level falls and the lid seal fails.
Drop, Lid Failure in Underground (Accident Scenario W3)	0.01	Same as Accident Scenario W1, but it occurs in the underground.
Drop, Puncture, Lid Failure in Underground (Accident Scenario W4)	0.01	Same as Accident Scenario W2, but it occurs in the underground.
Container Fire (Accident Scenario W5)	1E-4 (<8 PE-Ci) <1E-6 (>8 PE-Ci)	Contents of a drum in an underground disposal room spontaneously combusts prior to panel closure.
Hoist Failure (Accident Scenario W6)	<1E-6	Waste hoist braking system fails and fully loaded hoist falls to the bottom of shaft. Both CH-TRU and RH-TRU waste loads were evaluated.
Roof Fall (Accident Scenario W7)	0.01, Panel 1 < 1E-6, other panels	A portion of a disposal room roof falls prior to panel closure, crushing drums and causing lid seal failures.
RH-TRU Waste Canister Breach (Accident Scenario W8)	1E-4 to 1E-6	RH-TRU waste canister is breached Waste Handling Building operations.

Potential radiological consequences would be substantially higher than hazardous chemical consequences, which are very small for most accident cases. Estimated results for members of the public, the maximally exposed noninvolved worker, and the maximally exposed involved worker are presented below.

The greatest radiological consequences of facility accidents under Action Alternative 3 would be the same as the greatest consequences under the Action Alternative 2 subalternatives because characteristics of the thermally-treated and grouted waste forms were assumed to be the same. However, average radionuclide concentrations in the treated waste under the Action Alternative 2 subalternatives would realistically be two to five times higher than that of Action Alternative 3 waste. Therefore, average accident consequences for the Action Alternative 2 subalternatives would be higher than those for Action Alternative 3. For the disposal room roof failure (Accident Scenario W7), the consequences of postulated accidents under Action Alternative 3 would be less than those under the Proposed Action and Action Alternative 1 by at least a factor of ten. The grout treatment increases waste volume by 20 percent overall, and therefore reduces average concentrations by 20 percent, as well. The grouted waste is less likely to release particles of respirable size in the event of a container breach caused by a minor accident. However, in the event of a hoist failure, the more uniform, grouted waste matrix (as compared to waste treated to planning-basis WAC) is more likely to shatter upon impact into respirable particles. Consequences of the hoist failure would be approximately five to seven times higher than those estimated for waste treated to planning-basis WAC under the Proposed Action and Action Alternative 1. Radiological consequences of accidents under Action Alternative 3 are shown in Table 5-72.

Table 5-72
Radiological Consequences of WIPP Disposal Accidents for Action Alternative 3

Accident Scenarios	Population (LCFs)	MEI (probability of LCF)	Maximally Exposed Noninvolved Worker (probability of LCF)	Maximally Exposed Involved Worker (probability of LCF)
Drop, Lid Failure in Waste Handling Building (Accident Scenario W1)	9E-4	1E-5	1E-5	3E-3
Drop, Puncture Lid Failure in Waste Handling Building (Accident Scenario W2)	9E-4	1E-5	1E-5	3E-3
Drop, Lid Failure in Underground (Accident Scenario W3)	9E-4	1E-5	1E-5	3E-3
Drop, Puncture, Lid Failure in Underground (Accident Scenario W4)	9E-4	1E-5	1E-5	3E-3
Container Fire (Accident Scenario W5)	5E-3	7E-5	6E-5	Not Credible
Hoist Failure (CH-TRU, RH-TRU) (Accident Scenario W6)	CH-TRU: 29 RH-TRU: 9	CH-TRU: 0.6 RH-TRU: 0.1	CH-TRU: 0.5 RH-TRU: 0.1	See Footnote a
Roof Failure (Accident Scenario W7)	0.02	2 E-4	2 E-4	See Footnote a
RH-TRU Canister Breach (Accident Scenario W8)	0	0	0	0

[a] These consequences could range from negligible (workers not present, or warned of the falling hoist and evacuated) to catastrophic (all workers in the immediate vicinity killed by accident debris)

Note: This table presents estimates of the consequences of accident scenarios and does not reflect the frequency (or probability) of the accident occurring.

Public

Population consequences from WIPP disposal accidents were estimated for the 22.5 degree sector west of the site, which includes the city of Carlsbad. The population in this sector is 25,629 and would be affected greater than any other section in the surrounding 80-kilometer (50-mile) region. Consequences to the MEI were evaluated at the point of closest public access to the DOE Exclusive Use Area boundary and the least atmospheric dispersion of facility exhaust ventilation air, which would be the location of maximum consequence. This point was 300 meters (990 feet) south of the Exhaust Filter Building. No credit was taken for HEPA filtration from either the Exhaust Filter Building or the Waste Handling Building.

Radiological consequences from accidents would be higher than consequences from hazardous chemicals. The accident with the largest potential radiological consequence to the population and the MEI would be the failure of a fully loaded waste hoist carrying CH-TRU waste (Accident Scenario W6). Up to 29 LCFs could occur in the exposed population, and the MEI could experience a 0.6 probability of an LCF. The roof fall accident (Accident Scenario W7) would result in the highest potential carcinogenic hazardous chemical consequence, with an estimated 7×10^{-7} cancers occurring in the exposed population and an estimated 1×10^{-8} probability of cancer for the MEI. No fatalities due to toxicological effects would be expected. Noncarcinogenic consequence analyses based on ERPGs indicated potentially life-threatening exposures to methylene chloride and beryllium from a hoist failure accident and less serious consequences from lead, mercury, and carbon tetrachloride exposures. Consequences of the roof fall could involve serious, but not life-threatening exposures to 1,1,2,2,-tetrachloroethane releases and less serious consequences from carbon tetrachloride releases.

Maximally Exposed Noninvolved Worker

The maximally exposed noninvolved worker at WIPP was assumed to be located at the location of least atmospheric dispersion, 300 meters (990 feet) south of the Exhaust Filter Building, which is the same location as the MEI. The stack that exhausts the underground ventilation is elevated and, as a result, the location of least plume dispersion is some distance from the release point. Radiological consequences shown in Table 5-72 may be slightly lower than those for the MEI because of the small difference in the radiation dose-to-LCF conversion factors for workers and members of the public. The hazardous chemical consequences would be identical to those of the MEI.

Maximally Exposed Involved Worker

The potentially highest consequences to an involved worker would be underground from failure of a fully loaded waste hoist (Accident Scenario W6) or roof fall (Accident Scenario W7). These consequences could range from negligible (workers not present or warned of the falling hoist and evacuated) to catastrophic (all workers in the immediate vicinity killed by accident debris). Four workers would be expected to be routinely involved in underground operations and potentially at risk from these accidents.

Radiological consequences of accidents to the maximally exposed involved worker from noncatastrophic accidents are shown in Table 5-72. The highest radiological consequences would come from an accident causing three drums to breach (Accident Scenarios W1-W4), both with a 3×10^{-3} probability of an LCF. No fatalities due to hazardous chemical effects would be expected.

These same accidents, however, evaluated by ERPG ratios, might result in irreversible, non-life-threatening consequences from methlyene chloride and 1,1,2,2-tetrachloroethane exposure.

5.4.11 Industrial Safety

Five fatalities from industrial accidents would occur under Action Alternative 3 during waste treatment at all treatment sites. This result was estimated by adjusting the physical-hazard fatality estimate of the WM PEIS.

Under Action Alternative 3, WIPP operational activities would be essentially the same as those conducted under the Proposed Action but would last approximately 190 years rather than 35 years. Decommissioning activities would be the same as those for the Proposed Action. Estimated industrial safety impacts to WIPP workers under Action Alternative 3 are presented in Table 5-73. Oversight and inspections by the MSHA and adherence to OSHA regulations would probably reduce actual occurrences below these estimated values.

Table 5-73
Industrial Safety Impacts from WIPP
Operations and Decommissioning for Action Alternative 3

Years	Injury/Illness			Fatalities		
	Construction	Operations	Total	Construction	Operations	Total
Operations 1998-2200	118	6,650	6,768	0.2	6.6	6.8
Decommissioning 2200-2210	187	96	283	0.3	0.1	0.4
Total	305	6,746	7,051	0.5	6.7	7.3

5.4.12 Long-Term Performance

This section presents the potential impacts associated with long-term performance of the WIPP repository for Action Alternative 3 evaluated for the 10,000-year period after the site is closed. These impacts were estimated based on computer simulations that predicted radionuclide and heavy metal releases from TRU waste in the repository under undisturbed and disturbed conditions. Analysis was conducted using the same methods as those used for the Proposed Action and other action alternatives; additional information is presented in Appendix H. The waste volume emplaced would be 334,000 cubic meters (11.8 million cubic feet) of CH-TRU waste and 66,000 cubic meters (2.3 million cubic feet) of RH-TRU waste. The repository size was increased from the 10 panels of the Proposed Action to 71 panels to accommodate the increased waste volume. The radionuclide inventory was increased to 7.3×10^6 Ci in CH-TRU waste and 5.1×10^6 Ci in RH-TRU waste, essentially the same as the inventories of Action Alternatives 1 and 2. There were similar increases in heavy metal inventories. Additional information on the radionuclide and heavy metal inventories is provided in Appendix A.

The four cases below were analyzed for Action Alternative 3. The cases are the same as the Proposed Action and other action alternatives but include alternative-specific differences, such as repository size and radionuclide and heavy metal inventories.

- Case 16 considered undisturbed repository conditions. Median parameter values were used for input variables where probability distributions have been defined.

- Case 17 considered disturbed conditions resulting from a borehole assumed to pass through the repository and intercept a pressurized brine reservoir in the Castile Formation. Median parameters values were used for input variables where probability distributions have been defined.

- Case 18 was the same as Case 16 but used 75th percentile parameter values for input variables where probability distributions have been defined.

- Case 19 was the same as Case 17 but used 75th percentile parameter values for input variables where probability distributions have been defined.

5.4.12.1 Impacts of Undisturbed Conditions

For Action Alternative 3, the extent of radionuclide (predominantly Pu-238, Pu-239, and Am-241) migration for undisturbed conditions 10,000 years after closure for Case 18 (75th percentile parameter values) would be very similar to that shown for Case 8 of Action Alternative 1 in Figure 5-3. Figure 5-3 shows the locations in the modeled region where the concentration of total radionuclide activity in the brine, summed over 30 radionuclides, is equal to 1 pCi per liter (1×10^{-9} Ci per cubic meter). A total heavy metal concentration of one part per billion (1×10^{-3} milligrams per cubic meter) showed approximately the same extent of migration from the repository as the one pCi per liter level of total radionuclide activity concentration.

Approximately the same vertical and lateral migration of radionuclides and heavy metals would occur under Action Alternative 3 as for the Proposed Action and other action alternatives. Total radionuclide concentrations of one pCi per liter would extend about 20 meters (65 feet) below the repository, 40 meters (130 feet) above the repository, and about 1,900 meters (6,200 feet) laterally.

Analysis of undisturbed repository conditions (Cases 16 and 18) during the first 10,000 years showed that no radionuclides or heavy metals would be released to the Culebra Dolomite. No total radionuclide activity concentrations greater than 1 pCi per liter or heavy metal concentrations greater than 1 part per billion would be found beyond the 5-kilometer (3-mile) subsurface lateral boundary. There would be no release to the accessible environment and therefore no human health impact. Additional information is provided in Appendix H.

5.4.12.2 Impacts of Disturbed Conditions

This section presents the impacts of two exposure scenarios evaluated for disturbed conditions for Action Alternative 3.

Surface Release Caused by Drilling into the Repository

The human health impacts of drilling into the repository (Case 17 and Case 19) were evaluated for a drilling crew member and a well-site geologist. These individuals were assumed to be exposed to waste material brought to the land surface by drilling, as described in Section 5.1.12.2 and Appendix H. Under Action Alternative 3, 20 repository panels would hold both CH-TRU and

RH-TRU waste and 51 waste panels would hold only RH-TRU waste; therefore, a drilling event could contact CH-TRU, RH-TRU, or both CH-TRU and RH-TRU waste.

The estimated radionuclide releases to the ground surface from a drilling intrusion for Case 17 (median parameter values) would be 2.2, 0.1, and 2.3 Ci, respectively, for CH-TRU waste, RH-TRU waste, and both CH-TRU and RH-TRU waste. For Case 19 (75th percentile parameter values), the estimated radionuclide releases would be 3.0, 0.15, and 3.0 Ci, respectively, for CH-TRU waste, RH-TRU waste, and both CH-TRU and RH-TRU waste. The releases would be mainly of Pu-238, Pu-239 and Am-241 for all events. Heavy metal releases from these drilling intrusions would be 5, 22, and 18 kilograms (11, 49, and 39 pounds) from CH-TRU waste, RH-TRU waste, and both CH-TRU and RH-TRU waste for Case 17. For Case 19, the heavy metal releases would be 7, 30, and 23 kilograms (15, 65, and 52 pounds) from CH-TRU waste, RH-TRU waste, and both CH-TRU and RH-TRU waste. Additional information is provided in Appendix H.

The radiological impacts to a drilling crew member for Case 17 (median parameter values) would be a 1×10^{-4}, 7×10^{-6}, and 1×10^{-4} probability of an LCF, respectively, from CH-TRU waste, RH-TRU waste, and both CH-TRU and RH-TRU waste. For Case 19 (75th percentile parameter values), the probability of an LCF would be a 3×10^{-4}, 1×10^{-5}, and 3×10^{-4} probability of an LCF for the same respective panel types. Most of the impact would be due to the inadvertent ingestion of drill cuttings (ranging from 83 percent to about 96 percent), with less impact from external radiation dose. Americium-241 would be the major dose contributor. Ingestion of heavy metals under this scenario would result in a 1.5×10^{-8}, 1.0×10^{-9}, and 1.5×10^{-8} probability of cancer incidence, respectively, for intrusions into CH-TRU waste, RH-TRU waste, and both CH-TRU and RH-TRU waste. There would be no noncarcinogenic impacts expected from ingestion of the metals becaues all hazard indices would be much less than one. Impacts of exposure to VOCs were not analyzed (see Appendix H), but were expected to be bounded by impacts of VOC exposure under WIPP disposal accidents (see Appendix G). There would be a 2×10^{-7} probability of a cancer incidence. Some short-term toxicological effects from inhalation of VOCs could occur under these assumptions (see Appendix G).

Radiological impacts to the well-site geologist from external radiation exposure for Case 17 (median parameter values) would be a 2×10^{-9} probability of an LCF from CH-TRU waste and a 1×10^{-9} probability of an LCF from RH-TRU waste. For Case 19 (75th percentile parameter values), the radiological impacts would be a 2×10^{-9} probability of an LCF from CH-TRU waste and a 4×10^{-9} probability of an LCF from RH-TRU waste. Am-241 and U-234 were major external dose contributors in CH-TRU and RH-TRU waste for Case 17 and in CH-TRU waste for Case 19, while Sr-90 and Cs-137 were the major external dose contributors in RH-TRU waste for Case 19.

Drilling through the Repository into a Pressurized Brine Reservoir

Impacts of drilling through the repository into a pressurized brine reservoir were analyzed as described in Section 5.1.12.2 and in Appendix H, using information specific to Action Alternative 3 where appropriate. Analysis of radionuclide and heavy metal migration for this scenario 10,000 years after closure for Case 17 (median parameter values) showed there would be no radionuclide or heavy metal releases into the Culebra Dolomite or the accessible environment.

The extent of radionuclide (predominantly Pu-238, Pu-239, and Am-241) migration for disturbed conditions at 10,000 years after closure for Case 19 (75th percentile parameters values) were very similar to the results of Case 9 (also 75th percentile parameter values) for Action Alternative 1 and are presented schematically in Figure 5-4. Total radionuclide activity concentrations of one pCi per liter are shown. Simulations showed radionuclides migrated upward and downward into the borehole and penetrated into rocks directly in contact with the borehole for a limited distance. For Case 19 only (not Case 17), migration extends upward into the Culebra Dolomite at 10,000 years. Migration also extends downward in the borehole (for both Cases 17 and 19) to the Castile Formation and into the brine reservoir. This would occur after the initial pressure in the pressurized brine pocket dissipates and equilibrates with pressures in the repository and overlying units penetrated by the borehole. A total heavy metal concentration of one part per billion (1×10^{-3} milligrams per cubic meter) showed approximately the same extent of migration from the repository as the one pCi per liter level of total radionuclide activity concentration in Figure 5-4. Predicted brine pressures and additional modeling information is provided in Appendix H.

Impacts of radionuclide and heavy metal migration to the accessible environment were evaluated for Case 19 (75th percentile parameter values) since a release of contaminants into the Culebra Dolomite was indicated for this case only. The exposure scenario was the same as that evaluated for the Proposed Action and other action alternatives, for an individual consuming beef from cattle using the water from a stock well 3 kilometers (2 miles) from the point of intrusion. Results are presented only for partial mining conditions since calculated impacts for full mining conditions were significantly lower (see Section H.8.2). Radiological impacts would be negligible, with a 2×10^{-27} probability of an LCF. The dominant dose contributor was Pu-239. Ingestion of heavy metals from consumption of contaminated beef was also found to result in negligible impacts, with a probability of cancer incidence of 3×10^{-25}. No noncarcinogenic impacts would be expected. Additional information is presented in Appendix H.

5.4.13 Reducing WIPP Operations for Action Alternative 3

As noted in Chapter 3, stakeholders requested that the Department discuss in greater detail the changes to impacts should the Department reduce the period of operations for WIPP under Action Alternative 3. The period of operations is 190 years, but it could be reduced to 75 years by constructing an additional waste handling building for RH-TRU waste, constructing four new shafts, and tripling the number of excavation and emplacement crews. Additional costs would total $80 million in capital costs and $165 million in annual operating costs.

No additional impacts would be expected at treatment facilities because the facilities and their periods of operation would be identical to those discussed earlier.

The time to ship to WIPP from the treatment facilities would decrease from 190 years to 63 years. The aggregate nonradiological impacts would be the same as those described earlier, except that they would occur within the shorter time period. The accident-free radiological impacts to occupational and nonoccupational populations were reported as aggregate impacts over the entire shipping campaign; therefore, no increase in impacts would be noted. However, because the MEI would be exposed to more shipments, the estimated exposure to the MEI would be three times higher. All accident impacts would be identical to those described earlier.

Because the size of the WIPP underground facility would remain the same, and because the new facility would be constructed within the footprint of the repository, land use, biological resource,

and cultural resource impacts would be similar to those described earlier in this section. Construction of the new waste handling building would increase the air quality impacts slightly for the period of construction. Other air quality impacts would be negligible. Noise impacts would triple because the rate of shipments through Carlsbad would triple. Water quality and infrastructure impacts may be impacted by the new facilities and additional work crews.

Human health impacts would decrease for lag storage. The impacts to the public, noninvolved workers, and involved workers over the entire operations period would remain the same, but they would be compressed into about one-third of the time. Impacts to the MEIs would triple because the waste emplaced during a lifetime would triple. Industrial safety impacts would decrease by approximately 50 percent, considering the shorter operations period, construction of facilities, and an increase in the number of workers. There would be no change in long-term performance assessment results.

The greatest change in Action Alternative 3 results would be in life-cycle costs, which would drop from $59.67 billion in 1994 dollars ($18.03 billion discounted) to $43.02 billion ($13.30 billion discounted) should only trucks be used. Life-cycle costs should regular rail transportation be used would decrease from $55.17 billion ($17.42 billion discounted) to $38.52 billion ($11.91 billion discounted), and life-cycle costs should dedicated rail transportation be used would decrease from $68.52 billion ($19.21 billion discounted) to $51.87 billion ($16.04 billion discounted).

5.5 IMPACTS OF NO ACTION ALTERNATIVE 1

This section describes the environmental impacts associated with the implementation of No Action Alternative 1. Two subalternatives are included, one similar to Action Alternative 2A and the other similar to Action Alternative 2B. Under this alternative, the Basic Inventory and the Additional Inventory (including the PCB-commingled waste) would be shipped to treatment sites for treatment using a thermal process, but no waste would be shipped to WIPP for disposal. Instead, under No Action Alternative 1A, waste would remain at six sites in aboveground, retrievable storage. These sites are Hanford, INEEL, LANL, SRS, RFETS, and ORNL. Under No Action Alternative 1B, waste would remain at four sites in aboveground, retrievable storage. These sites are Hanford, INEEL, SRS and ORNL. The total consolidated, pretreatment volume of waste to be treated under this alternative would be 313,000 cubic meters (11 million cubic feet) (see Tables 3-12 through 3-15). A detailed description of No Action Alternative 1 is given in Section 3.2.5.

5.5.1 Land Use and Management

Land use impacts due to treatment under No Action Alternatives 1A and 1B would be similar to those under the Proposed Action discussed in Section 5.1.1. The WM PEIS estimated that treatment facilities would not require more than 1 percent of the available land, and the Department would have a great deal of flexibility when determining the locations of such facilities (DOE 1997). The Department would be able to minimize impacts to on-site land use and would be able to avoid conflicts with off-site land use plans. It also would be able to avoid sensitive or inappropriate habitats, including flood plains, wetlands, known cultural resource areas, and the habitats of threatened or endangered species. Before the sites for the treatment facilities would be selected, site-wide or project level NEPA reviews would be conducted.

Land use requirements due to storing the waste for an indefinite period of time would probably increase the land use impacts at the treatment and storage sites. The storage facilities, though, are not likely to increase the amount of land needed for overall operations at these sites to more than 1 or 2 percent of that available. Land use needs for the storage facilities, therefore, are not likely to conflict with other planned activities or impact sensitive or inappropriate areas.

At WIPP, under No Action Alternatives 1A and 1B, decommissioning and closure would begin immediately. No surface marking system would be necessary because no waste would be disposed of underground. Decommissioning, therefore, would be less extensive than under the Proposed Action and Action Alternatives 1, 2A, 2B, 2C, and 3. Surface structures in the Property Protection Area would be dismantled and removed, and the existing salt pile would either be returned to the underground, sold, or disposed of. The disturbed areas, estimated not to exceed 20 hectares (50 acres), would be returned to pre-WIPP condition to the extent possible. The restrictions of the LWA would probably be lifted and the land returned to BLM.

5.5.2 Air Quality

Air quality impacts from TRU waste treatment at the sites would be similar to those presented for Action Alternatives 2A and 2B in Section 5.3.2. For No Action Alternative 1A, the levels of criteria pollutants exceeding 10 percent of the applicable annual regulatory standard during operation of treatment facilities would be those for CO at the RFETS (24 percent) and PM_{10} at INEEL (10 percent) (See Appendix C for details) (DOE 1997). Under No Action Alternative 1B, the levels of criteria pollutants exceeding 10 percent would be PM_{10} at INEEL (10 percent). RFETS, LLNL, NTS, and ANL-E, are in nonattainment areas for some pollutants (See Appendix C for details) (DOE 1997). In nonattainment areas, activities that introduce new sources of emissions are regulated under the General Conformity Rule. In attainment areas, regulations for the PSD of ambient air quality apply. In both cases, a permit is required for sources that will result in emissions equal to or greater than the limits set by pertinent regulations.

Of hazardous or toxic air pollutant releases, only radionuclide releases could exceed 10 percent of the applicable regulatory standard. For No Action Alternative 1A, treatment-related radiological releases could reach 134 percent of the NESHAP standard at LANL. For No Action Alternative 1B, treatment-related releases could reach 10 percent at INEEL (DOE 1997). Postulated waste treatment-related releases above the regulatory standard would require mitigation measures, such as HEPA filters, to ensure they remained below the allowable limit.

At WIPP, potential air quality impacts due to decommissioning activities under No Action Alternatives 1A and 1B would be similar to those under the Proposed Action for decommissioning of the aboveground structures. There would be no construction of berms and permanent markers, so overall air quality impacts at WIPP would be less than for the Proposed Action. This alternative would also require building retrievable storage facilities at six DOE sites for the consolidation, treatment, and storage of TRU waste. Any impacts from construction of the storage facility would be from fugitive dust and equipment emissions. PM_{10} emissions may occur due to such construction; dust suppression would be used to limit these short-term impacts.

5.5.3 Biological Resources

The biological impacts at the treatment sites under No Action Alternatives 1A and 1B would be the same as those for Action Alternatives 2A and 2B. Construction and operation of the treatment and

storage facilities should not affect populations of nonsensitive plant and animal species. Terrestrial wildlife species probably would not be affected by airborne emissions nor by spills into aquatic environments due to traffic accidents (DOE 1997). Threatened and endangered species appear at all of the proposed treatment sites; however, impacts to these species would depend on the actual location of the facility at a particular site. Site selection would be conducted following appropriate Endangered Species Act consultation and site-wide or project-level NEPA review during which such impacts would be assessed and mitigated, if necessary. Critical habitats and the habitats of endangered, threatened, and proposed species would be avoided, and appropriate consultation, monitoring, and mitigation measures would be undertaken, as necessary.

At WIPP, No Action Alternatives 1A and 1B would entail beginning the immediate decommissioning of the site, including dismantling all aboveground structures and closing all shafts. No waste would be disposed of, so there would be no permanent aboveground marking of the underground waste disposal area. Only about 20 hectares (50 acres) would be disturbed. Therefore, decommissioning and closure at the WIPP site would have less potential impact than the Proposed Action.

5.5.4 Cultural Resources

At the treatment sites, cultural resource impacts would be the same for this alternative as for the Proposed Action. Construction and operation of TRU waste treatment and storage facilities could adversely affect cultural resources, but site-level cultural resource surveys would be conducted, and protection measures established, where necessary, when specific facility construction locations are proposed. Appropriate Native American tribes would be consulted, if necessary. These surveys would be in conjunction with site-wide or project-specific NEPA reviews.

At WIPP, no impacts to known cultural resource properties are anticipated under this alternative.

5.5.5 Noise

The WM PEIS stated that treatment sites would probably be located in industrial areas along high-volume highway corridors; therefore, ambient noise levels are not likely to increase substantially. Still, the WM PEIS states that some sensitive receptors may be affected. Assessment of these impacts would be conducted in site-wide or project-specific NEPA documents when the treatment facilities are proposed. Noise impacts due to transportation of waste to or from the treatment sites also was not evaluated in the WM PEIS. Overall, though, less transportation would be conducted under this alternative because no waste would leave the treatment sites for disposal at WIPP. The transportation noise impacts, therefore, would be negligible.

There would be no impacts from truck or rail transportation to WIPP because waste transportation activities to WIPP would not be initiated.

5.5.6 Water Resources and Infrastructure

Water resource and infrastructure impacts at the treatment and storage sites under No Action Alternatives 1A and 1B would be the same as under Action Alternatives 2A and 2B (See Section 5.3.6). During decommissioning at WIPP, there would be a decreasing need and use of water, power, and wastewater systems and a decreasing demand on-site transportation infrastructure. There would be no demand or use of these resources following decommissioning.

5.5.7 Socioeconomics

Estimated life-cycle costs and potential socioeconomic impacts for No Action Alternatives 1A and 1B are presented in the following subsections.

5.5.7.1 Life-Cycle Costs

Under No Action Alternatives 1A and 1B, WIPP would not receive waste. All waste volumes would remain indefinitely at the sites where treated. The CH-TRU waste portion of the waste inventory would be packaged every 20 years. Impacts from this packaging were evaluated over a 100-year period. No Action Alternatives 1A and 1B include the same waste treatment sites and the same waste volumes as those in Action Alternatives 2A and 2B. Cost for storage facilities are included with the cost of the treatment facilities. The WIPP site costs reflect a 10-year period of decommissioning. The waste transport costs reflect shipments between small sites and the treatment sites.

The transportation options include using trucks, regular rail, and dedicated rail services. Life-cycle costs for No Action Alternative 1A and 1B include additional costs of $700 million and $3.8 billion, respectively, to account for treatment to planning-basis WAC of waste to be shipped for treatment. These costs were based on dual treatment (WAC and thermal) of 34 percent and 18.4 percent, respectively, of the total waste volume. The total life-cycle cost of No Action Alternative 1A (shown in Table 5-74) vary slightly with mode of transportation: $30.28 billion ($17.09 billion when discounted) for truck, $30.24 billion ($17.07 billion when discounted) for regular-class rail service, and $30.46 billion ($17.19 billion when discounted) for dedicated-class rail service.

Table 5-74
Life-Cycle Costs for No Action Alternative 1A (in millions of 1994 dollars) [a]

Life-Cycle Cost Information	Basic Inventory			Additional Inventory			Total	Total Discounted
	CH-TRU Waste	RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU Waste	RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU and RH-TRU Waste
Treatment and Storage Facilities	12,670	3,280	15,950	13,040	370	13,410	29,360	16,280
Transport by Truck	30	10	40	30	0	30	70	40
Transport by Regular Train	10	0	10	20	0	20	30	20
Transport by Dedicated Train	110	30	140	110	0	110	250	140
WIPP Decommissioning [b]	N/A	N/A	N/A	N/A	N/A	N/A	850	770
Total Life-Cycle Cost (Truck)	12,700	3,290	15,990	13,070	370	13,440	30,280	17,090
Total Life-Cycle Cost (Regular Rail)	12,680	3,280	15,960	13,060	370	13,430	30,240	17,070
Total Life-Cycle (Dedicated Rail)	12,780	3,310	16,090	13,150	370	13,520	30,460	17,190

[a] The methods and assumptions used to estimate the various cost components are described in Appendix D. Actual totals may differ due to rounding.

[b] The WIPP decommissioning cost of $850 million is applied to the total column only because it is not attributed to storage of CH-TRU or RH-TRU waste but must be considered in the life-cycle cost of the alternative.

N/A = Not Applicable

The total life-cycle costs of No Action Alternative 1B (shown in Table 5-75) vary slightly depending on the mode of transportation, ranging from $32.77 billion ($18.47 billion when discounted) for regular-class rail service to $33.79 billion ($19.04 billion when discounted) for dedicated-class rail service.

Table 5-75
Life-Cycle Costs for No Action Alternative 1B (in millions of 1994 dollars) [a]

Life-Cycle Cost Information	Basic Inventory			Additional Inventory			Total	Total Discounted
	CH-TRU Waste	RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU Waste	RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU and RH-TRU Waste
Treatment and Storage Facilities	13,700	3,550	17,250	14,100	350	14,450	31,760	17,610
Transport by Truck	100	30	130	110	0	110	240	130
Transport by Regular Train	70	20	90	70	0	70	160	90
Transport by Dedicated Train	510	130	640	530	10	540	1,180	650
WIPP Decommissioning	N/A	N/A	N/A	N/A	N/A	N/A	850	770
Total Life-Cycle Cost (Truck)	13,800	3,580	17,380	14,210	350	14,560	32,850	18,520
Total Life-Cycle Cost (Regular Rail)	13,770	3,570	17,340	14,170	350	14,520	32,770	18,470
Total Life-Cycle Cost (Dedicated Rail)	14,210	3,680	17,890	14,630	350	14,990	33,790	19,040

[a] The methods and assumptions used to estimate the various cost components are described in Appendix D. Actual totals may differ due to rounding.

N/A = Not Applicable

5.5.7.2 Economic Impacts

TRU waste treatment activities would support direct, indirect, and induced jobs. No Action Alternative 1A would support approximately 29,300 jobs in the ROIs of the six treatment sites (Hanford, INEEL, LANL, ORNL, RFETS, and SRS). No Action Alternative 1B would support approximately 29,800 jobs in the ROIs of four treatment sites (Hanford, INEEL, ORNL, and SRS).

Estimates of the impacts of No Action Alternative 1 on employment, income, and the production of goods and services within the WIPP ROI are presented in Table 5-76. These regional impacts are estimated on the basis of a constant declining operating budget over a 10-year decommissioning period (from 1998 to 2008). Over this 10-year period, direct employment at the WIPP facility would be reduced at an annual rate of 10 percent of the 1998 employment level of 1,095 workers, or 110 workers per year. Accordingly, the WIPP site would employ about half its present work force by the year 2003. It is possible, however, that a more aggressive (front-loaded) downsizing could result in equivalent job losses within a two-year period, assuming an exponentially declining WIPP budget. Compared to WIPP operations levels assumed for all action alternatives, approximately 3,500 jobs (1,095 direct and 2,443 indirect) could be lost in the WIPP ROI, over a period of about 10 years. The accompanying annual reduction in labor income and output of goods and services in the ROI could be $126 million and $317 million, respectively, from those which could occur were waste disposal operations to take place. These impacts would be concentrated in the Carlsbad area of the ROI.

Table 5-76
Economic Impacts Within the WIPP ROI for No Action Alternative 1

Economic Effects	Total Output of Goods and Services (in millions of 1994 dollars)	Total Employment and Part-Time Jobs	Total Labor Income (in millions of 1994 dollars)	Carlsbad Output of Goods and Services (in millions of 1994 dollars)	Carlsbad Employment (Full- and Part-Time Jobs)	Carlsbad Labor Income (in millions of 1994 dollars)
Direct – Average Annual	51	493	23	43	441	21
Indirect & Induced – Average Annual	92	1,099	34	77	983	30
Total – Average Annual	143	1,592	57	120	1,424	51
Total – Operations (10 years)	1,427	15,921 [a]	572	1,202	14,238 [a]	509

[a] Job-years (number of annual jobs supported multiplied by the number of years in the project).

5.5.8 Transportation

The transportation impacts presented in this section for No Action Alternatives 1A and 1B are the impacts due to transporting the waste to the treatment sites (details are included in Appendix E).

5.5.8.1 Route Characteristics and Shipment Projections

The number of shipments was estimated to be 538 and 8,466 CH-TRU waste shipments for No Action Alternatives 1A and 1B, respectively. The number of RH-TRU waste shipments were estimated to be 8,254 for both No Action Alternatives 1A and 1B. The methods used to estimate the number of shipments were the same as those presented in Section 5.1.8.1. The total estimated one-way mileage for consolidation of TRU waste under No Action Alternatives 1A and 1B is presented in Table 5-77.

Table 5-77
One-Way Waste Transportation Miles for No Action Alternative 1

Alternative	CH-TRU Waste	RH-TRU Waste	Total
No Action Alternative 1A	292,000	4,900,000	5,192,000
No Action Alternative 1B	8,545,000	4,900,000	13,445,000

5.5.8.2 Accidents, Injuries, Fatalities, and Pollution-Related Health Effects

The population impacts for No Action Alternatives 1A and 1B are presented in Table 5-78. For No Action Alternative 1A, the total number of accidents, injuries, and fatalities over the entire shipping campaign were estimated to be 5, 4 and 0.3, respectively. Similarly, for No Action Alternative 1B, the accidents, injuries, and fatalities were estimated to be 13, 12, and 1, respectively. Also presented in Table 5-78 are the pollution-related health effects.

Table 5-78
Population Impacts from Truck Transportation for No Action Alternative 1

Category	No Action Alternative 1A	No Action Alternative 1B
Nonradiological Impacts		
Number of Accidents	5	13
Number of Injuries	4	12
Number of Fatalities	0.3	1
Pollution Health Effects (fatalities)	0.03	0.07
Accident-Free Radiological Impacts (LCFs)		
Occupational	0.02	0.07
Nonoccupational		
Stops	0.4	0.8
Sharing Route	0.02	0.05
Along Route	0.01	0.02
Nonoccupational (LCFs) - Total	0.4	0.9
Aggregate Radiological Population Impacts for Truck Transportation Accidents (LCFs)		
CH-TRU Waste	5.6E-3	0.02
RH-TRU Waste	1.2E-3	1.2E-3
Total CH-TRU and RH-TRU Waste	6.8E-3	0.02

5.5.8.3 Accident-Free Radiological Impacts from Truck Transportation

The method used to calculate the accident-free radiological impacts under No Action Alternatives 1A and 1B was based on the consolidation of waste at the treatment sites. Table 5-78 presents a summary of the accident-free radiological impacts under No Action Alternatives 1A and 1B.

5.5.8.4 Radiological Impacts from Truck Transportation Accidents

Two types of analyses were conducted for SEIS-II radiological impacts due to accidents. The first estimated impacts over the entire shipping campaign, and the second estimated impacts from four bounding case accidents. For the first analysis, the impacts were estimated based on the number of shipments and the eight accident severity categories presented in RADTRAN. For No Action Alternatives 1A and 1B, the radiological impacts from accidents summed over all shipments are presented in Table 5-78.

For the bounding case accidents, it was estimated that the impacts would be the same as those reported for truck transportation under the Proposed Action (see Section 5.1.8.4). The analyses were based on an assumption that only one TRUPACT-II or RH-72B would be breached in a bounding case accident. Though the waste would be treated thermally under No Action Alternatives 1A and 1B, the treatment would not occur until after the transportation.

5.5.8.5 Hazardous Chemical Impacts from Severe Truck Transportation Accidents

As reported previously in Section 5.1.8.5, exposures to hazardous chemical releases from a severe truck transportation accident would present negligible impacts to the exposed population.

5.5.8.6 Impacts from Rail Transportation

Table 5-79 presents a summary of the transportation impacts for both regular and dedicated rail under No Action Alternatives 1A and 1B. The rail transportation impacts were estimated by adjusting the transportation impacts for truck shipments as described in Section 5.2.8.6 and Appendix E.

Table 5-79
Impacts of Rail Transportation for No Action Alternative 1

Impact Category	No Action Alternative 1A	No Action Alternative 1B
Aggregate Traffic Related Fatalities		
Regular Rail	0.2	0.5
Dedicated Rail	2.8	7
Aggregate Accident-Free Radiological Impacts (LCFs)		
Occupational	8.6E-4	3.7E-3
Nonoccupational		
Stops	0.05	0.09
Sharing Route	2.3E-4	4.6E-4
Along Route	0.02	0.04
Nonoccupational - Total	0.07	0.1
Aggregate Radiological Population Impacts for Rail Transportation Accidents (LCFs)		
CH-TRU Waste	5.6E-3	0.02
RH-TRU Waste	1.2E-3	1.2E-3
Total CH-TRU and RH-TRU Waste	6.8E-3	0.02

Radiological accident impacts from shipping by rail summed over all shipments for No Action Alternatives 1A and 1B are presented in Table 5-79 along with traffic-related fatalities and accident-free radiological impacts.

The impacts from bounding case accidents were estimated to be the same as those reported for Action Alternative 1 rail accident analyses, where it was assumed that two TRUPACT-IIs or RH-72Bs would be breached in an accident. The greatest impact was found when a conservative inventory was assumed, 32 LCFs in the population and a 0.12 probability of an LCF to the MEI.

5.5.9 Human Health Impacts from Waste Treatment and Storage Operations

This section presents human health impacts to the public, noninvolved workers, and involved workers from waste treatment and 100 years of managed storage under No Action Alternatives 1A and 1B. The estimates include the impacts from overpacking CH-TRU waste storage containers every 20 years. There would be no disposal of waste at WIPP under this alternative.

No Action Alternative 1 eliminates the risk from PCB-commingled TRU waste at the three sites known to store such waste: 242 cubic meters (8,550 cubic feet) at Hanford, 461 cubic meters (16,300 cubic feet) at INEEL, and 19 cubic meters (670 cubic feet) at Mound. Under No Action Alternative 1, PCBs in the waste would be destroyed during treatment.

Impacts from waste treatment were adjusted from those presented in the WM PEIS; a description of these adjustments is provided in Appendix B. Like Action Alternatives 2A and 2B, No Action Alternatives 1A and 1B include thermal treatment of the Total Inventory. The VOCs in the waste

would be destroyed during thermal treatment, and heavy metals would be immobilized. Therefore, no routine releases of hazardous chemicals would occur in the subsequent waste storage operations. Thermal treatment also concentrates the waste and radionuclides into a smaller, denser volume. Denser waste matrices tend to decrease surface dose rates because of more self-absorption of the external radiation emitted by radionuclides in the waste. Worker radiological impacts reflect the impact of these factors. Appendix F provides additional information on the methods used to determine the impacts presented in this section.

5.5.9.1 Public

Impacts to the populations and to the MEIs under No Action Alternatives 1A and 1B are presented in this section; results are presented in Table 5-80. Impacts from waste treatment and managed storage operations are presented separately to show their relative impact contribution. Waste treatment and storage would take place at six DOE sites under No Action Alternative 1A and at four sites under No Action Alternative 1B. Population impacts were estimated for those members of the public residing within 80 kilometers (50 miles) of all treatment sites and all lag storage sites. The impacts to the MEIs from waste treatment and managed storage operations are presented for the highest individual waste treatment and storage sites. See Chapter 3 for additional information on where treatment and managed storage would occur under the subalternatives of No Action Alternative 1.

Waste Treatment

Radiological impacts to the public from waste treatment would be 2.4 and 2.3 LCFs under No Action Alternatives 1A and 1B, respectively. No cancer incidence would be expected in the total population from hazardous chemical exposure, with 3×10^{-7} cancers expected under both subalternatives. For radiological impacts, the MEI with the greatest impact would be at RFETS under No Action Alternative 1A (3×10^{-5} probability of an LCF) and at Hanford under No Action Alternative 1B (5×10^{-5} probability of an LCF). Impacts from hazardous chemicals in CH-TRU waste would not exceed a 2×10^{-11} probability of a cancer incidence at any site. No noncarcinogenic health effects are predicted. The maximum HIs for the MEI would be 2×10^{-8} (under No Action Alternative 1A) and 5×10^{-9} (under No Action Alternative 1B), and no health effect is predicted unless the HI is 1 or higher.

Long-Term Managed Storage

Only radiological impacts would result from long-term managed storage because VOCs would be removed by thermal treatment under No Action Alternative 1. No LCFs would be expected in the total population around the storage sites under any of the alternatives, with 1×10^{-3} and 7×10^{-4} LCFs expected under No Action Alternatives 1A and 1B, respectively. The MEI with the greatest impact would be at LANL for No Action Alternative 1A (2×10^{-7} probability of an LCF) and at ORNL for No Action Alternative 1B (2×10^{-9} probability of an LCF). No noncarcinogenic health effects would occur because there would be no exposure to hazardous chemicals.

Table 5-80
Lifetime Human Health Impacts to the Public from Waste Treatment and Storage Operations for No Action Alternatives 1A and 1B

Category	Waste Treatment Impacts		Storage Operations Impacts	
	Radiological (LCF) [a]	Hazardous Chemicals (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemicals (Cancer Incidence)
MEI [b, c]				
Basic Inventory				
1A CH-TRU Waste	3E-5 (R)	3E-13 (L)	2E-7 (L)	0
1B CH-TRU Waste	2E-5 (H)	3E-13 (I)	5E-9 (S)	0
RH-TRU Waste	4E-7 (O)	1E-11 (O)	1E-9 (O)	0
1A Total Waste	3E-5 (R)	1E-11 (O)	2E-7 (L)	0
1B Total Waste	2E-5 (H)	1E-11 (O)	5E-9 (S)	0
Total Inventory				
1A CH-TRU Waste	3E-5 (R)	5E-13 (I)	2E-7 (L)	0
1B CH-TRU Waste	5E-5 (H)	6E-13 (I)	1E-9 (S)	0
RH-TRU Waste	6E-7 (O)	2E-11 (O)	2E-9 (O)	0
1A Total Waste	3E-5 (R)	2E-11 (O)	2E-7 (L)	0
1B Total Waste	5E-5 (H)	2E-11 (O)	2E-9 (O)	0
Population [b]				
Basic Inventory				
1A CH-TRU Waste	2.2	5E-9	7E-4	0
1B CH-TRU Waste	1.1	2E-9	4E-4	0
RH-TRU Waste	0.02	2E-7	3E-5	0
1A Total Waste	2.2	2E-7	7E-4	0
1B Total Waste	1.1	2E-7	4E-4	0
Total Inventory				
1A CH-TRU Waste	2.3	9E-9	1E-3	0
1B CH-TRU Waste	2.3	4E-9	6E-4	0
RH-TRU Waste	0.02	3E-7	5E-5	0
1A Total Waste	2.4	3E-7	1E-3	0
1B Total Waste	2.3	3E-7	7E-4	0
Aggregate Total				
1A	2.4	3E-7	3E-3	0
1B	2.3	3E-7	2E-3	0

[a] The probability of an LCF occurring to the MEI, and the number of LCFs in the population.
[b] The MEI and populations evaluated for treatment and storage operations impacts are different.
[c] H = Hanford, L = LANL, O = ORNL, R = RFETS, S = SRS, I = INEEL

The aggregate total indicated in Table 5-80 refers to the impacts to the public expected over a 100-year operational period under No Action Alternative 1. The estimates reflect the impacts under the management of the Total Inventory of CH- and RH-TRU waste. No LCFs (3×10^{-3} LCFs) would be expected over the several generations exposed to the small potential routine releases of radioactive materials under incident-free operations.

5.5.9.2 Noninvolved Workers

Impacts to the noninvolved worker population and the maximally exposed noninvolved worker under No Action Alternatives 1A and 1B are presented in this section; results are presented in Table 5-81. A noninvolved worker is an employee who works at a site but is not directly involved in the treatment, storage, or handling of waste. Impacts from waste treatment and long-term managed storage are presented separately to show the relative contributions of these activities.

Noninvolved worker population impacts were estimated as the total for all treatment sites and all managed storage facilities. The impacts to the maximally exposed noninvolved worker from waste treatment and managed storage are presented for the highest individual waste treatment sites.

Table 5-81
Lifetime Human Health Impacts to Noninvolved Workers from Waste Treatment and Storage Operations for No Action Alternative 1

Category	Waste Treatment Impacts		Storage Operations Impacts	
	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)
Maximally Exposed Noninvolved Worker [b, c]				
Basic Inventory				
1A CH-TRU Waste	5E-5 (R)	1E-12 (I)	8E-7 (S)	0
1B CH-TRU Waste	7E-5 (H)	2E-12 (I)	8E-7 (S)	0
RH-TRU Waste	3E-7 (O)	6E-11 (O)	1E-8 (O)	0
1A Total Waste	5E-5 (R)	6E-11 (O)	8E-7 (S)	0
1B Total Waste	7E-5 (H)	6E-11 (O)	8E-7 (S)	0
Total Inventory				
1A CH-TRU Waste	5E-5 (R)	4E-12 (I)	1E-6 (S)	0
1B CH-TRU Waste	2E-4 (H)	4E-12 (I)	1E-6 (S)	0
RH-TRU Waste	5E-7 (O)	1E-10 (O)	2E-8 (O)	0
1A Total Waste	5E-5 (R)	1E-10 (O)	1E-6 (S)	0
1B Total Waste	2E-4 (H)	1E-10 (O)	1E-6 (S)	0
Population [b]				
Basic Inventory				
1A CH-TRU Waste	0.09	3E-9	0.02	0
1B CH-TRU Waste	0.06	2E-9	0.02	0
RH-TRU Waste	4E-4	7E-8	2E-4	0
1A Total Waste	0.09	7E-8	0.02	0
1B Total Waste	0.06	7E-8	0.02	0
Total Inventory				
1A CH-TRU Waste	0.1	7E-9	0.02	0
1B CH-TRU Waste	0.1	6E-9	0.02	0
RH-TRU Waste	6E-4	1E-7	2E-4	0
1A Total Waste	0.1	1E-7	0.02	0
1B Total Waste	0.1	1E-7	0.02	0
Aggregate Total				
1A	0.1	1E-7	0.06	0
1B	0.1	1E-7	0.06	0

[a] The probability of an LCF occurring to the maximally exposed noninvolved worker, and the number of LCFs in the population.
[b] The MEI and populations evaluated for treatment and storage operations impacts are different.
[c] H = Hanford, I = INEEL, L = LANL, O = ORNL, R = RFETS, S = SRS

Waste Treatment

No radiation-related LCFs would be expected in the total noninvolved worker population at the waste treatment sites, with 0.1 LCFs under both subalternatives. No cancer incidence would be expected in the total noninvolved worker population from hazardous chemical exposure, with a 1×10^{-7} probability of a cancer incidence under both of the subalternatives. The maximally exposed noninvolved worker for radiological impacts would be at RFETS under No Action Alternative 1A (5×10^{-5} probability of an LCF) and at Hanford under No Action Alternative 1B (2×10^{-4} probability of an LCF). Impacts would not exceed a 1×10^{-10} probability of cancer incidence at any site. No noncarcinogenic health effects are predicted. The maximum HIs for the maximally exposed noninvolved worker would be 2×10^{-7} (under No Action Alternative 1A) and 1×10^{-7} (under No Action Alternative 1B), and no health effect is predicted unless the HI is 1 or higher.

Long-Term Managed Storage

Only radiological impacts would result from managed storage because VOCs would be removed by thermal treatment. No LCFs would be expected in the total noninvolved worker population during the 35-year working lifetime assumed for workers at the managed storage sites (0.02 LCFs would be expected under both subalternatives). The maximally exposed noninvolved worker would be at SRS for both subalternatives; a 1×10^{-6} probability of an LCF was calculated. No noncarcinogenic health effects would occur because there would be no exposure to hazardous chemicals.

The aggregate total indicated in Table 5-81 refers to the impacts to the noninvolved worker population expected over the 100-year operational period under No Action Alternative 1. The estimates reflect the impacts under the management of the Total Inventory of CH- and RH-TRU waste. No LCFs (0.06 LCFs) would be expected over the several generations exposed to the small potential routine releases of gaseous radionuclides under incident-free operations.

5.5.9.3 Involved Workers

Potential impacts to involved workers from waste treatment and storage operations are presented in Table 5-82. Up to 1.7 and 1.3 LCFs could occur in involved worker populations from radiation exposure during waste treatment under No Action Alternatives 1A or 1B, respectively. No cancer incidence would be expected to occur from hazardous chemical exposure (6×10^{-5} cancers for No Action Alternative 1A and 9×10^{-5} cancers for No Action Alternative 1B), and no noncarcinogenic health effects would occur (maximum exposure index of 6×10^{-3}).

No impacts from radiation exposure would be expected from waste storage during the 100-year storage period evaluated (≤0.4 LCF) under either subalternative. All worker exposures to radiation and hazardous chemicals would be controlled to ALARA levels. Administrative controls such as worker and area monitoring, rotation of workers to reduce exposures, and standard operating procedures would be used to limit exposures.

Table 5-82
Lifetime Human Health Impacts to Involved Workers
from Waste Treatment and Storage Operations for No Action Alternative 1 [a]

Category	Waste Treatment Impacts		Storage Operations Impacts	
	Radiological (LCF)	Hazardous Chemicals (Cancer Incidence)	Radiological (LCF)	Hazardous Chemicals (Cancer Incidence)
Population				
Basic Inventory				
1A CH-TRU Waste	0.7	2E-5	0.09	0
1B CH-TRU Waste	0.5	4E-5	0.08	0
RH-TRU Waste	0.2	9E-6	≤0.09	0
1A Total Waste	0.9	3E-5	≤0.2	0
1B Total Waste	0.7	5E-5	≤0.2	0
Total Inventory				
1A CH-TRU Waste	1.4	5E-5	0.2	0
1B CH-TRU Waste	1.1	8E-5	0.2	0
RH-TRU Waste	0.3	1E-5	≤0.2	0
1A Total Waste	1.7	6E-5	≤0.4	0
1B Total Waste	1.3	9E-5	≤0.4	0
Aggregate Total				
1A	1.7	6E-5	≤1.1	0
1B	1.3	9E-5	≤1.1	0

[a] The workers considered for treatment impacts and storage impacts are different.

Different populations of involved workers would be involved in routine surveillance and monitoring activities and in waste overpacking operations. All sites were assumed to overpack 5 percent of the CH-TRU waste Total Inventory annually during the 100 years of storage evaluated. Each CH-TRU waste container would be overpacked every 20 years, although if this alternative were selected the Department would probably begin efforts to design longer lasting CH-TRU waste containers.

The impacts from CH-TRU waste would be from the external radiation dose received during waste container handling. Potential radiological impacts from inhalation of radioactive gases released from waste containers would be negligible. Involved worker impacts from storage activities were calculated by assuming waste handlers would spend 2 hours every workday at 1 meter (3.3 feet) from the CH-TRU waste containers and were assumed to be exposed over a 35-year career. Container dose rates were decay-corrected over 35 years. The first 35 years of packaging operations would be the period of greatest potential impact because radioactive decay would reduce the radioactivity of the waste over time. Table 5-83 shows how potential annual radiological impacts to involved worker populations would decrease over the storage period because of radioactive decay.

Overpacking of RH-TRU waste containers was not considered during the 100-year storage period because of the greater RH-TRU waste container integrity. Impacts from RH-TRU waste storage would be less because of remote RH-TRU waste handling and greater administrative controls for RH-TRU waste. Therefore, no specific RH-TRU waste storage impact estimates were made. Storage impacts under this alternative would be assessed in future site-wide or project-specific NEPA reviews.

The aggregate totals indicated in Table 5-82 refer to the impacts to the involved worker population expected over the 100-year operational period under No Action Alternatives 1A and 1B. Less than 1.1 LCFs would be expected in the several generations of involved workers exposed via external exposures from storage operations. The radiological impact estimates reflect the results of the aggregate impacts analyses presented in detail in Appendix F.

Table 5-83
Annual Involved Worker Population Impacts from CH-TRU Waste Overpacking Operations for No Action Alternatives 1A and 1B (LCFs)

Location	Worker Population	Years Since Operations Began					
		1	20	40	60	80	100
No Action Alternative 1A							
Hanford	14	9E-3	6E-3	4E-3	3E-3	2E-3	1E-3
INEEL	14	4E-3	3E-3	3E-3	3E-3	3E-3	3E-3
LANL	4	6E-4	6E-4	5E-4	5E-4	4E-4	4E-4
RFETS	1	3E-3	3E-3	2E-3	2E-3	2E-3	2E-3
SRS	2	1E-4	1E-4	1E-4	1E-4	9E-5	9E-5
No Action Alternative 1B							
Hanford	14	9E-3	6E-3	4E-3	3E-3	2E-3	1E-3
INEEL	19	7E-3	7E-3	6E-3	6E-3	6E-3	6E-3
SRS	2	1E-4	1E-4	1E-4	1E-4	9E-5	9E-5

5.5.10 Facility Accidents

This section describes potential impacts of facility accidents at the treatment sites from thermal treatment of waste and from indefinite waste storage after treatment under No Action Alternatives 1A and 1B. The difference between No Action Alternatives 1A and 1B is that no CH-TRU waste would be treated or stored at LANL and RFETS under No Action Alternative 1B. No waste would be disposed of under the two No Action Alternative 1 subalternatives; therefore, no WIPP disposal accidents were analyzed.

5.5.10.1 Waste Treatment Accidents

The impacts of waste treatment accidents under both No Action Alternative 1 subalternatives would be the same as those under Action Alternatives 2A and 2B (see Section 5.3.10.1). In both cases, the waste would be treated thermally at the same sites.

5.5.10.2 Waste Storage Accidents

Potential facility accident impacts under both No Action Alternative 1 subalternatives would be very similar to those presented in Section 5.3.10.2 for Action Alternatives 2A and 2B because stored waste would have been thermally treated. Because WIPP would not be an indefinite storage site under either No Action Alternative 1 subalternative some of the maximum values reported for the MEI in Section 5.3.10.2 would change. These differences are as follows:

- The maximum radiological impacts to the MEI from the drum puncture accident (Accident Scenario S1) would occur at LANL with an 8×10^{-9} probability of an LCF. Maximum impacts from the earthquake or other natural event (Accident Scenario S3) would also be at LANL, with a 4×10^{-3} probability of an LCF.

- The maximum heavy metal carcinogenic impacts to the MEI from the drum puncture accident (Accident Scenario S1) would occur at LANL, with a 1×10^{-16} probability of cancer. The maximum heavy metal carcinogenic impacts to the MEI from the earthquake or other natural event (Accident Scenario S3) would occur at Hanford, with a 1×10^{-9} probability of cancer.

Additional accident analysis information is presented in Appendix G.

As waste would be maintained in storage over long periods of time, the accident risk would be expected to change. Radioactive decay would reduce the amount of radioactivity in the waste. Impacts from a drum puncture (Accident Scenario S1) would be expected to decrease because of reduced radioactivity and overpacking reducing the potential amount of particulates spilled from the waste container in the event of a breach. Impacts from an earthquake (Accident Scenario S3) may decrease because of overpacking or may remain stable because of deterioration of the waste form over time. The deterioration may result in an increase in the amount of particulates released in the event that containers are breached.

5.5.11 Industrial Safety

Nine and seven fatalities would occur from industrial accidents during waste treatment at all treatment sites under No Action Alternatives 1A and 1B, respectively. These estimates were adjusted from the physical-hazard fatality estimates of the WM PEIS.

Under No Action Alternatives 1A and 1B, industrial safety impacts could occur as a result of decommissioning the WIPP site and from constructing and operating long-term TRU waste storage facilities at the treatment sites. Results are presented in Table 5-84. WIPP decommissioning activities would be the same as those discussed under the Proposed Action, except that activities would begin in 1998. In all likelihood, the initial work force would be smaller and the decommissioning period shorter, resulting in fewer injuries and illnesses. No fatalities would be projected.

Table 5-84
Industrial Safety Impacts from WIPP
Decommissioning and Site Storage for No Action Alternative 1

Years	Injury/Illness			Fatalities		
	Construction	Operations	Total	Construction	Operations	Total
WIPP Decommissioning 1998-2008	187	96	283	0.3	0.1	0.4
Indefinite Storage at Sites (packaging and monitoring for 100-year period)	124	213	337	0.2	0.2	0.4

Long-term storage impacts were evaluated for a 100-year period. It was assumed that CH-TRU waste storage facilities would be constructed. Waste would be moved to new facilities every 50 years. RH-TRU waste storage facilities would necessarily be more robust to provide therequired shielding and would be constructed only once during the period and would last 100 years. CH-TRU waste would be repackaged every 20 years (5 percent per year), while RH-TRU waste, stored in drums inside welded steel canisters, would not be repackaged during the 100-year period. Each year approximately 20 percent of the CH-TRU waste and 5 percent of the RH-TRU waste would be monitored in a manner requiring worker attention to individual containers (e.g., smearing the exterior of containers for contamination and checking lid seals or welds). These activities would be accomplished remotely for RH-TRU waste. No fatalities would occur during the 100-year storage period.

5.5.12 Long-Term Performance

Under No Action Alternatives 1A and 1B, TRU waste would continue to be generated and put into monitored, retrievable storage. There would be no shipment of waste to WIPP, and no long-term radiological or hazardous chemical impacts to the environment or human health would occur at the WIPP site. DOE would indefinitely maintain institutional control and provide long-term monitoring and maintenance of storage facilities. As a consequence, adverse health effects for the general public while DOE maintained control would be minimal, and the principal adverse effects, which also would be small, would be related to occupational activity at the facility. Health effects would continue at such levels for the indefinite future.

The Department realizes that loss of institutional control is a possibility for any long-term storage alternative. Therefore, an analysis of the potential impacts from long-term environmental release under No Action Alternative 1A and 1B was conducted. The analysis was similar to that presented in Appendix I for No Action Alternative 2; however, the waste form generated by the thermal treatment process would substantially reduce those potential impacts. Radionuclides and heavy

metals would be incorporated into a more dense and durable waste form that would limit the release of waste into the accessible environment. It was assumed that the glass waste form uniformly reduced the infiltration release rate by a factor of 1×10^{-4}. This factor is based on studies conducted on the dissolution rate of glass waste forms and their effect on contaminant releases to the environment. VOCs would be removed in the treatment process and would not be present in emplaced waste. Once waste containers degrade, direct release from a thermally-treated waste form (e.g., metal slag or glass) would depend on the rate of corrosion and dissolution of metal or glass and natural forces responsible for erosion rather than leaching.

No radiological or hazardous chemical impacts to individuals or populations would be expected over 10,000 years. The number of aggregate LCFs for all sites over 10,000 years was estimated to be less than 8×10^{-4} LCFs for No Action Alternative 1A and 3×10^{-4} LCFs for No Action Alternative 1B for the Total Inventory. [1]

5.6 IMPACTS OF NO ACTION ALTERNATIVE 2

This section describes the environmental impacts associated with the implementation of No Action Alternative 2. If No Action Alternative 2 were implemented, WIPP would be closed, newly generated waste would be treated to planning-basis WAC, all other waste would be left as is, and all of the waste would remain at the sites where it is currently located or would be generated. A detailed description of No Action Alternative 2 is presented in Section 3.2.6.

5.6.1 Land Use and Management

Construction of treatment facilities under this alternative would be minimal. Only newly generated waste would be treated. All other waste would continue to be stored as it has been to date. Therefore, minimal land use impacts would be expected.

At WIPP, land use impacts under No Action Alternative 2 would be similar to those for WIPP under No Action Alternative 1, discussed in Section 5.5.1.

5.6.2 Air Quality

Very limited treatment would be done under No Action Alternative 2. Only newly generated waste would be treated. All other waste would be left as it has been stored to date. Also, any treatment conducted would be to planning-basis WAC; no thermal or shred and grout treatment would be conducted. For TRU waste treatment, the only criteria pollutant postulated to exceed 10 percent of the applicable annual regulatory standard during operation of treatment facilities would be CO at RFETS (17 percent). No radiological, hazardous, or toxic air pollutants would exceed 10 percent of the applicable regulatory standard during normal accident-free treatment (DOE 1997). At WIPP, potential air quality impacts due to decommissioning activities under No Action Alternative 2 would be similar to those under No Action Alternative 1 described in Section 5.5.2.

5.6.3 Biological Resources

Because very limited treatment would be done under No Action Alternative 2 and because current storage facilities would be used, minimal biological impacts would be expected due to construction

[1] People who might intrude upon the stored waste could receive radiation doses that would greatly exceed current regulatory limits.

and operation of treatment and storage facilities. Potential impacts on biological resources at WIPP under No Action Alternative 2 would be similar to those under No Action Alternatives 1A and 1B, described in Section 5.5.3.

5.6.4 Cultural Resources

Because very limited treatment would be done under this alternative, minimal cultural resource impacts, if any, would be expected. Also, no potential cultural resources impacts at WIPP would be expected under this alternative.

5.6.5 Noise

Potential noise impacts under No Action Alternative 2 would be negligible. No waste would be transported and only newly generated waste would be treated.

5.6.6 Water Resources and Infrastructure

Under No Action Alternative 2 there would be minimal incremental infrastructure impacts from water, wastewater, and power usage due to treatment to planning-basis WAC and storage. During decommissioning at WIPP, there would be a decreasing need and use of water, power, and wastewater systems and on-site transportation infrastructure. There would be no demand or use of these resources following decommissioning.

5.6.7 Socioeconomics

Estimated life-cycle costs and potential socioeconomic impacts for No Action Alternative 2 are presented in the following subsections.

5.6.7.1 Life-Cycle Costs

The life-cycle costs of No Action Alternative 2 are reported in Table 5-85. Under No Action Alternative 2, WIPP would not be used as a waste disposal site. Closure of the WIPP site would follow a 10-year period of decommissioning, beginning in 1998 and ending in 2008. There would be no waste transportation under No Action Alternative 2. Waste generator sites would treat and store CH-TRU and RH-TRU waste inventories for 35 years. Waste treatment operations at these sites cover only newly generated waste. Current waste management practices would continue. The total life-cycle costs of the No Action Alternative 2 would be $2.49 billion ($1.68 billion when discounted), reflecting life-cycle costs at the treatment sites and decommissioning costs at the WIPP site.

5.6.7.2 Economic Impacts

TRU waste treatment activities would support direct, indirect, and induced jobs. Under No Action Alternative 2, only the newly generated defense waste would be treated, and approximately 2,300 jobs would be supported throughout the ROIs of the ten major generator sites (ANL-E, Hanford, INEEL, LANL, LLNL, Mound, NTS, ORNL, RFETS, and SRS).

The economic impacts at the WIPP site would be the same as those for No Action Alternatives 1A and 1B, presented in Section 5.5.7.2.

Table 5-85
Life-Cycle Costs for No Action Alternative 2 (in millions of 1994 dollars) [a]

Cost Information	Basic Inventory			Total Discounted
	CH-TRU Waste	RH-TRU Waste	CH-TRU and RH-TRU Waste	CH-TRU and RH-TRU Waste
Treatment of Newly Generated Waste	880	380	1,260	700
Storage of all Waste	270	110	380	210
WIPP Decommissioning [b]	N/A	N/A	850	770
Total Life-Cycle Cost	1,150	490	2,490	1,680

[a] The methods and assumptions used to estimate the various cost components are described in Appendix D. Actual totals may differ due to rounding.
[b] The WIPP decommissioning cost of $850 million is applied to the total column only because it is not attributed to either CH-TRU or RH-TRU waste at the storage sites but must be considered in the life-cycle cost of this alternative.

N/A = Not Applicable

5.6.8 Transportation

No waste would be transported under No Action Alternative 2, so there would be no transportation impacts.

5.6.9 Human Health Impacts from Waste Treatment and Management Operations

This section presents human health impacts to the public, noninvolved workers, and involved workers from treatment of newly generated TRU waste to meet the planning-basis WAC and from continuation of current waste management practices (aboveground waste storage) under No Action Alternative 2. There would be no disposal of waste at WIPP under this alternative. Impacts from waste treatment were adjusted from those presented in the WM PEIS. A description of these adjustments is provided in Appendix B.

5.6.9.1 Public

Impacts to the populations and to the MEIs under No Action Alternative 2 are presented in this section; results are presented in Table 5-86. Impacts from treatment of newly generated waste and continued waste management/storage operations are presented separately to show their relative contribution to the total impact. Waste treatment and management/storage would take place at multiple DOE sites. Population impacts were estimated for those members of the public residing within 80 kilometers (50 miles) of all treatment sites and all management/storage sites. The impacts to the MEIs from waste treatment and waste management/storage operations are presented for the highest individual sites. See Chapter 3 for additional information on where treatment and management/storage would occur under No Action Alternative 2.

Waste Treatment

No LCFs (1×10^{-3} LCF) or cancer incidence (4×10^{-7} cancers) would be expected in the total population around the waste treatment sites. The MEI with the greatest impact would be at LANL for radiological impacts (8×10^{-8} probability of an LCF) and at ORNL for hazardous chemical impacts (2×10^{-11} probability of a cancer incidence). No noncarcinogenic health effects are predicted. The maximum HI for the MEI would be 8×10^{-11}, and no health effect is predicted unless the HI is 1 or higher.

Table 5-86
Lifetime Human Health Impacts to the Public
from Waste Treatment and Storage Operations Under No Action Alternative 2

Category	Waste Treatment Impacts		Storage Operations Impacts	
	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)
MEI [b, c]				
Basic Inventory				
CH-TRU Waste	8E-8 (L)	2E-12 (X)	2E-6 (O)	4E-8 (L)
RH-TRU Waste	1E-10 (L)	2E-11 (O)	2E-9 (O)	2E-8 (O)
Total Waste	8E-8 (L)	2E-11 (O)	2E-6 (O)	4E-8 (L)
Population [b]				
Basic Inventory				
CH-TRU Waste	1E-3	7E-8	0.01	2E-3
RH-TRU Waste	1E-6	4E-7	3E-5	3E-4
Total Waste	1E-3	4E-7	0.01	2E-3
Aggregate Total	1E-3	4E-7	0.01	2E-3

[a] The probability of an LCF occurring to the MEI, and the number of LCFs in the population.
[b] The MEI and populations considered for treatment impacts and storage impacts are different.
[c] L = LANL, O = ORNL, X = LLNL

Continued Management/Storage

No LCFs would be expected in the total population around the lag storage sites (1×10^{-2} LCF); no cancer incidence (2×10^{-3} cancers) would be expected in the total population from hazardous chemical exposure. The MEI with the greatest impact would be at ORNL for radiological impacts (2×10^{-6} probability of an LCF) and at LANL for hazardous chemical impacts (4×10^{-8} probability of a cancer incidence). No noncarcinogenic health effects would occur. The maximum HI for any MEI would be 4×10^{-4}.

The aggregate total indicated in Table 5-86 refers to the impacts to the public expected over the 100-year operational period under No Action Alternative 2. The estimates reflect the impacts under the management of the Total Inventory of CH- and RH-TRU waste. No LCFs (0.03 LCFs) or cancer incidence (6×10^{-3} cancers) would be expected over the several generations that would be exposed to the small potential routine releases of radioactive or hazardous materials under incident-free operations.

5.6.9.2 Noninvolved Workers

Impacts to the noninvolved worker population and the maximally exposed noninvolved worker under No Action Alternative 2 are presented in this section; results are presented in Table 5-87. A noninvolved worker is an employee who works at a site but is not directly involved in the treatment, management, or storage of waste. Impacts from waste treatment and management/storage are presented separately to show the relative impact contribution of these activities. Waste treatment and management/storage would take place at multiple DOE sites. Noninvolved worker population impacts were estimated as the total for all treatment sites and all management/storage sites. The impacts to the maximally exposed noninvolved worker from waste treatment and management/storage are presented for the highest individual waste treatment sites.

Table 5-87
Lifetime Human Health Impacts to Noninvolved Workers
from Waste Treatment and Storage Operations Under No Action Alternative 2

Category	Waste Treatment Impacts		Storage Operations Impacts	
	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)	Radiological (LCF) [a]	Hazardous Chemical (Cancer Incidence)
Maximally Exposed Noninvolved Worker [b, c]				
Basic Inventory				
CH-TRU Waste	4E-8 (L)	5E-12 (X)	8E-6 (O)	2E-7 (I)
RH-TRU Waste	5E-11 (L)	1E-10 (O)	3E-5 (O)	3E-8 (H)
Total Waste	4E-8 (L)	1E-10 (O)	4E-5 (O)	2E-7 (I)
Population [b]				
Basic Inventory				
CH-TRU Waste	8E-5	2E-8	0.04	4E-3
RH-TRU Waste	8E-8	1E-7	8E-5	5E-4
Total Waste	8E-5	1E-7	0.04	2E-3
Aggregate Total	8E-5	1E-7	0.04	2E-3

[a] The probability of an LCF occurring to the maximally exposed noninvolved worker, and the number of LCFs in the population.
[b] The noninvolved workers considered for treatment impacts and operations impacts are different.
[c] H = Hanford, I = INEEL, L = LANL, O = ORNL, X = LLNL

Waste Treatment

No LCFs (8×10^{-5} LCF) or cancer incidence (1×10^{-7} cancers) would be expected in the total noninvolved worker population at the waste treatment sites. The maximally exposed noninvolved worker would be at LANL for radiological impacts (4×10^{-8} probability of an LCF) and at ORNL for hazardous chemical impacts (1×10^{-10} probability of a cancer incidence). No noncarcinogenic health effects are predicted. The maximum HI for the maximally exposed noninvolved worker would be 8×10^{-10}, and no health effect is predicted unless the HI is 1 or higher.

Continued Management/Storage

No LCFs would be expected in the total noninvolved worker population at the management/storage sites (4×10^{-2} LCF); no cancer incidence (2×10^{-3} cancers) would be expected in the total noninvolved worker population from hazardous chemical exposure. The maximally exposed noninvolved worker would be at ORNL for radiological impacts (4×10^{-5} probability of an LCF) and at INEEL for hazardous chemical impacts (2×10^{-7} probability of a cancer incidence). No noncarcinogenic health effects would occur; the maximum HI for any maximally exposed noninvolved worker would be 1×10^{-3}.

The aggregate total indicated in Table 5-87 refers to the impacts to the noninvolved worker population expected over the 35-year operational period under No Action Alternative 2. No LCFs (0.1 LCFs) or cancer incidence (6×10^{-3} cancers) would be expected over the several generations that would be exposed to the small potential routine releases of radioactive or hazardous chemicals under incident-free operations.

5.6.9.3 Involved Workers

Potential impacts to involved workers from treatment of newly generated waste and storage operations under No Action Alternative 2 are presented in Table 5-88. No LCFs (0.4) would

occur in the total involved worker population from radiation exposure during waste treatment. No cancer (8×10^{-6} cancers) would be expected from hazardous chemical exposure, and no noncarcinogenic health effects would occur (maximum exposure index of 5×10^{-5}). Less than 1 radiation-related LCF, and less than 0.04 cancers from hazardous chemical exposure would be expected in the involved worker population from continued waste management and storage operations. All worker exposures to radiation and hazardous chemicals would be controlled to ALARA levels. Administrative controls such as worker and area monitoring, rotation of workers to reduce exposures, and standard operating procedures would be used to limit exposures.

Table 5-88
Lifetime Human Health Impacts to Involved Workers from Waste Treatment and Storage Under No Action Alternative 2

Category	Waste Treatment Impacts		Storage Operations Impacts	
	Radiological (LCF)	Hazardous Chemical (Cancer Incidence)	Radiological (LCF)	Hazardous Chemical (Cancer Incidence)
Population				
Basic Inventory				
CH-TRU Waste	0.3	8E-7	0.5	0.02
RH-TRU Waste	0.02	7E-6	≤0.5	≤0.02
Total Waste	0.4	8E-6	≤1	≤0.04
Aggregate Total	0.4	8E-6	≤1	≤0.04

The impacts from CH-TRU waste would be from the external radiation dose received during waste container handling. Potential radiological impacts from inhalation of radioactive gases released from waste containers would be negligible. Involved worker impacts from storage activities were calculated by assuming waste handlers would spend 2 hours every workday at 1 meter (3.3 feet) from the CH-TRU waste containers and were assumed to be exposed over a 35-year career. Container dose rates were decay-corrected over 35 years. Impacts from RH-TRU waste storage would be less than those for CH-TRU waste storage because of remote RH-TRU waste handling and greater administrative controls for RH-TRU waste.

The aggregate total indicated in Table 5-88 refers to the impacts to the involved worker population at the storage sites expected over the 35-year period (for operations) under No Action Alternative 2. Storage worker population impact estimates indicate that less than 3 LCFs and less than 0.1 cancers are expected over the several generations of involved workers exposed externally or via inhalation of hazardous chemicals.

5.6.10 Facility Accidents

Very limited treatment of waste would occur under No Action Alternative 2. Only newly generated waste would be treated, and that waste would be treated only to the planning-basis WAC. Also, no consolidation of waste would occur. Storage would be continued for an indefinite period of time. No waste would be disposed of at WIPP. WIPP disposal accidents, therefore, were not assessed for this alternative.

5.6.10.1 Waste Treatment Accidents

The impacts of waste treatment accidents under No Action Alternative 2 would be the same as those under the Proposed Action (see Section 5.1.10.1) because the small portion of waste that would be treated, would be treated to planning-basis WAC.

5.6.10.2 Waste Storage Accidents

Potential storage accident impacts under No Action Alternative 2 would be similar to those presented in Section 5.2.10.2 for Action Alternative 1 because that waste that would be treated at all would be treated to planning-basis WAC prior to storage. For that portion of the No Action Alternative 2 waste that would not be treated to planning-basis WAC, accident frequencies and potential impacts could be somewhat higher than those presented in Section 5.2.10.2.

5.6.11 Industrial Safety

At the waste generator sites less than one fatality (0.7) would occur from industrial accidents under No Action Alternative 2 during waste treatment at all generator sites. This result was estimated by adjusting the physical-hazard fatality estimate of the WM PEIS.

Under No Action Alternative 2, industrial safety impacts could occur as a result of decommissioning the WIPP site and from continued management of TRU waste at the generator-storage sites. Estimated impacts are presented in Table 5-89. WIPP decommissioning activities were assumed to be the same as discussed under the Proposed Action except that activities would begin in 1998. In all likelihood, the initial work force would be smaller and the decommissioning period shorter, resulting in fewer injuries and illnesses. No fatalities would be projected. Current waste practices were assumed to continue at the generator-storage sites for the 35-year operations period. No industrial fatalities were projected from continued waste storage at the sites.

Table 5-89
Industrial Safety Impacts from WIPP Decommissioning and Site Waste Management Under No Action Alternative 2

Years	Injury/Illness			Fatalities		
	Construction	Operations	Total	Construction	Operations	Total
WIPP Decommissioning 1998-2008	187	96	283	0.3	0.1	0.4
Waste at Sites 1998-2033	N/A	190	190	N/A	0.2	0.2

N/A = Not Applicable

5.6.12 Long-Term Performance

No Action Alternative 2 was included among those alternatives considered in the FEIS and SEIS-I. The FEIS and SEIS-I analyzed the environmental consequences of No Action Alternative 2 under several different assumptions and conditions. In general, it was estimated that if DOE would

provide effective monitoring and maintenance of storage facilities, adverse health effects for the general public would be quite small, and the principal adverse effects, also small, would be related to occupational activity at the facilities. These health effects would continue at such levels for the indefinite future under the hypothesis of DOE control.

However, if DOE were to lose institutional control of storage facilities, it was estimated that intruders could receive substantial radiation doses, a situation that could persist for the indefinite future. In addition, contaminants in TRU waste stored in shallow burial trenches and surface storage facilities would eventually be released and would persist in the surrounding environments at the treatment sites exposing on-site and off-site populations to chronic health impacts.

The ROD for the FEIS, published on January 28, 1981, determined as part of the basis for decision that the No Action Alternative was "unacceptable." This determination was made at the time because of the potential impacts of natural, low probability events and human intrusion at storage facilities after governmental control of the site is lost. In SEIS-I, a summary of the FEIS analysis was provided and the same conclusion was reached in its ROD, published on June 21, 1990.

The long-term impacts of continuing current TRU waste management practices and loss of institutional control were reexamined under No Action Alternative 2 for SEIS-II. The effect of human intrusion was reexamined because of the changed estimated volumes and inventories of future generated TRU waste (see Appendix A). This analysis also examined the long-term impacts

INTRUSION AT WIPP AND AT GENERATOR-STORAGE SITES

The intrusion scenarios and potential impacts for the WIPP repository evaluated under the Proposed Action and Action Alternatives 1, 2, and 3 are very different from those for the generator-storage sites evaluated under No Action Alternatives 1 and 2.

Intrusion into TRU waste at WIPP is limited by the repository's 655-meter (2,150-foot) depth below the surface and remote location. The most likely direct intrusion scenario is penetration of the repository by hydrocarbon drilling. DOE has estimated the most likely number of intrusions into WIPP to be 5, with a probability of about 0.17 over a 10,000-year evaluation period. A limited amount of waste would be brought to the surface (less than 1 cubic meter) and would impact only a few members of the public directly associated with the drilling activity. This scenario, evaluated in SEIS-II, showed only a slight risk to the MEI. WIPP intrusion could result in the possibility of contamination migrating from the repository to the accessible environment through the borehole. Indirect intrusion, such as a well drilled for stock water (water in the vicinity of WIPP is not suitable for drinking or irrigation), would result in very low impacts to people eating stock exposed to this water.

In contrast, waste in surface facilities or shallow-buried storage would be easily accessible in the event of loss of institutional control, under the no action alternatives. There are multiple DOE sites that currently store TRU waste, some near population centers. Direct intrusion could occur through such common mechanisms as basement or building excavation, road building, pipeline or utility emplacement, scavenging, and casual intrusion. Indirect intrusion into contamination dispersed by any of the above activities or natural processes could be by gardening or farming activities. SEIS-II has evaluated potential impacts of intrusion and release of material under the no action alternatives. Under No Action Alternative 1, people who might intrude upon stored waste could receive radiation doses that would greatly exceed current regulatory limits. For waste in unconsolidated waste forms, evaluated under No Action Alternative 2, long-term and repeated intrusion activities could result in thousands of radiation-related LCFs over a 10,000-year evaluation period.

of environmental releases of contaminants from stored TRU waste at the major generator-storage sites. No TRU waste would be transported to WIPP and current WIPP operations would cease after a short decommissioning period. Thus, no long-term radiological or hazardous chemical impacts to the environment or human health would occur at the WIPP site under this alternative.

This section provides a summary of long-term impacts from stored TRU waste at the major generator-storage sites for 10,000 years following the loss of institutional control. The analysis of human health impacts estimated the impacts of TRU waste as a source of direct exposure and as a contaminant source for release to surface and subsurface exposure points in the environment. Scenarios analyzed included exposure to waterborne and airborne releases of contaminants from waste stored in shallow earth-covered trenches or covered by earthen berms and to waste stored in exposed surface pads or in surface enclosures and buildings.

Impacts to human health from waste intrusion and long-term environmental release were estimated using methods outlined in Appendix I and in a technical supporting document (Buck et al. 1997). This analysis focused on the impacts of waste at seven of the 10 major sites because the majority (99 percent) of the waste is stored at these sites. Estimates for RH-TRU waste impacts were only made at sites storing RH-TRU waste which are Hanford, INEEL, LANL, and ORNL. For buried waste, no estimates of impacts were made for either CH-TRU or RH-TRU waste at LLNL and RFETS because neither of these sites currently store waste in buried configurations.

Exposure scenarios evaluated included acute exposures to intruders and chronic exposures to settlers. These exposures were assumed to occur at the site of the original waste storage location, with little dispersion of contamination prior to exposure. Exposure scenarios evaluated for buried waste included an acute exposure of a driller intruder and the chronic exposure of a gardener who was assumed to subsequently settle at the drilling site. Exposure scenarios evaluated for surface-stored waste included the acute exposure of a scavenger intruder and the chronic exposure of a farm family settling on the site of the former waste storage area.

Impacts were also evaluated for the long-term environmental release of stored waste over 10,000 years. Evaluated were scenarios for chronic exposure of a MEI and the population living within 80 kilometers (50 miles) of the former waste storage sites. This individual and population could be exposed from releases from both buried and surface-stored waste. The MEI was assumed to be located 300 meters (980 feet) away from the waste storage site, in the direction of groundwater flow. The distribution of the off-site populations were assumed to be characteristic of current populations around the sites.

Descriptions of these exposure scenarios for intruders and settlers and long-term environmental releases are provided in AppendixI.

Impacts of Exposure Scenarios

With the loss of institutional control, individuals could come into direct contact or be inadvertently exposed to waste that had been stored in shallow burial or surface storage facilities. The following sections describe the impacts that could result from exposure to radionuclides and hazardous chemicals in CH-TRU and RH-TRU waste for exposure scenarios, where individuals were assumed to be exposed at the original storage locations. Individuals were assumed to be exposed immediately after the loss of institutional control, minimizing reduction of impact through radioactive decay.

Impacts from Exposure to Buried Waste

The driller scenario is one where an individual was assumed to drill a well at the site of the waste storage locations and be exposed over a 5-day work week to waste material brought to the land surface by the drilling process.

Radiological impacts to a hypothetical driller exposed acutely for 5 days (1 work week) from CH-TRU waste would range from a 1×10^{-6} to 5×10^{-6} probability of an LCF for the five sites with buried CH-TRU waste. Impacts to the driller from RH-TRU waste would range from a 1×10^{-6} to 3×10^{-5} probability of an LCF for the four sites with buried RH-TRU waste. Sites with the highest impacts would be INEEL and ORNL for CH-TRU waste and Hanford for RH-TRU waste. These results are presented in Table 5-90. Health impacts from hazardous chemicals would be significant. The RH-TRU waste concentration for lead could be up to 3,000 times the PEL.

The gardener scenario is one in which an individual was assumed to prepare a garden at the drilling site and grow produce in soil containing waste material brought to the surface by the drilling. This individual was assumed to ingest produce grown in the contaminated soil for a period of 30 years and be exposed while working in the garden.

Table 5-90
Radiological Impacts to Inadvertent Intruders Following Loss of Institutional Control for Seven Major Generator-Storage Sites (probability of an LCF)

	Hanford	INEEL	LLNL	LANL	ORNL	RFETS	SRS
CH-TRU Waste Impacts							
Buried Waste							
Driller (acute)	1E-6	5E-6	N/A	2E-6	5E-6	N/A	4E-6
Gardener (chronic)	0.01	0.01	N/A	0.02	0.01	N/A	0.06
Surface Waste							
Scavenger (acute)	2E-03	2E-03	6E-04	3E-03	3E-03	0.02	0.01
Family Farm (chronic)	0.6	0.8	0.2	1	1	1	1
RH-TRU Waste Impacts							
Buried Waste							
Driller (acute)	3E-5	5E-6	N/A	1E-6	3E-6	N/A	N/A
Gardener (chronic)	0.04	9E-3	N/A	4E-3	7E-3	N/A	N/A
Surface Waste							
Scavenger (acute)	0.01	2E-03	N/A	7E-04	1E-03	N/A	N/A
Family Farm (chronic)	1	1	N/A	0.3	1	N/A	N/A

N/A = Not Applicable

Radiological impacts to a hypothetical gardener would range from a 0.01 to 0.06 probability of an LCF for the five sites with buried CH-TRU waste. Impacts to the gardener from RH-TRU waste would range from a 4×10^{-3} to 0.04 probability of an LCF for the four sites with buried RH-TRU waste. Sites with the highest impacts would be SRS for CH-TRU waste and Hanford for RH-TRU waste. These results are also presented in Table 5-90. The hazard index for mercury and lead are 77 and 3,900, respectively, for the gardener for RH-TRU waste. The lead hazard index is 36 for CH-TRU waste.

Impacts from Exposure to Surface-Stored Waste

The scavenger scenario is one where an individual was assumed to come into direct contact with the TRU waste on the surface for a 24-hour period. This intruder was assumed to be exposed by inhalation of resuspended contamination, external radiation, and inadvertent ingestion of contaminated soil while at the site.

Radiological impacts to a hypothetical scavenger from CH-TRU waste would range from a 6×10^{-4} to 0.02 probability of an LCF; all seven sites would have surface-stored CH-TRU waste. Impacts to the scavenger from RH-TRU waste would range from a 7×10^{-4} to 0.01 probability of an LCF for the four sites with buried RH-TRU waste. Sites with the highest impacts would be RFETS for CH-TRU waste and Hanford for RH-TRU waste. These results are presented in Table 5-90. Significant impacts would be seen from heavy metals. The concentration of heavy metals ranges from 5 times to 1,400 times the PEL for CH-TRU waste and up to 160,000 times the PEL for RH-TRU waste.

The farmer scenario is one in which a hypothetical framer lives and farms on a plot of land at the location of the surface-stored waste. The waste was assumed to have degraded to a point where it was indistinguishable from the surrounding land and soil. The maximally exposed farmer was assumed to be exposed by ingestion of contaminated food crops grown in the contaminated soil, inhalation of resuspended contamination, external radiation, and inadvertent ingestion of contaminated soil. Under this scenario, the members of the family would receive very high radiation doses in the first year of farming. The probability of an LCF would range from 0.2 to 1 for CH-TRU waste, with three of the seven sites evaluated having a probability of 1 in the first year. The probability of an LCF would range from 0.3 to 1 for RH-TRU waste, with 3 of 4 sites having a probability of 1. These results are presented in Table 5-90. Noncarcinogenic effects such as radiation pneumenitis in the lungs could also occur. Health impacts from hazardous chemicals would be significant as well. The hazard index ranges from 10 to 100,000 for CH-TRU waste and up to 5,200,000 for RH-TRU waste.

Impacts of Long-Term Environmental Release

For TRU waste stored in shallow burial trenches and surface storage facilities at generator-storage sites, contaminants would eventually be released to the surrounding environments after loss of institutional control. Contaminants within the buried or surface-stored waste would be leached and released to underlying soils and aquifer systems at depth. At most sites contaminants would eventually reach groundwater and migrate laterally to a downgradient receptor location. Contaminants might also eventually be discharged into nearby surface water bodies. Once in these surface-water systems, the public would be exposed to dilute concentrations of the contaminants in public water supplies.

Waste stored in surface facilities would also degrade and disperse contaminants in the environment by the processes of direct water and air erosion, deposition onto soils surrounding the site, and resuspension of contaminated soils in air. The surrounding populations would be exposed to these contaminants as they were redistributed into the environment by these cyclic and ongoing processes.

Radiological and chemical impacts were evaluated for MEIs and the populations surrounding seven major generator-storage sites (Hanford, INEEL, LANL, LLNL, ORNL, RFETS, and SRS).

Additional information is provided in Appendix I. Impacts to the MEI were evaluated for a groundwater exposure scenario and an air pathway exposure scenario. Under the groundwater exposure scenario, the MEI was assumed to be a member of a farm family living 300 meters (980 feet) downgradient of the waste storage areas at each of the sites. It was assumed that the family would engage in farming activities such as growing and consuming its own crops and livestock and would use contaminated groundwater as a source of drinking water and for watering the crops and animals. Under the air pathway exposure scenario the MEI was assumed to live at the point of maximum airborne contaminant concentration. This individual could be exposed via inhalation of resuspended contamination, ingestion of contaminated food crops grown in the contaminated soil, external exposure to the soil, and inadvertent ingestion of contaminated soil.

Impacts to off-site populations were also evaluated from long-term environmental releases to surface water and to air. For analyses of buried waste releases, all CH-TRU and RH-TRU waste was combined into a single waste disposal unit, and only the groundwater pathway was considered. For analyses of surface-stored waste releases, all CH-TRU and RH-TRU waste was combined into a single waste storage unit and was allowed to be released to all pathways.

Impacts to the MEIs for the maximum 70-year lifetime over 10,000 years of environmental release of contaminants are presented in Table 5-91 for the seven major generator-storage sites. Radiological impacts to the MEI would range from a 3×10^{-6} probability of an LCF at ORNL to a 4×10^{-3} probability of an LCF at INEEL. Carcinogenic hazardous chemical impacts to the MEI would range from a 1×10^{-7} probability of cancer incidence at LANL to a 5×10^{-3} probability of cancer incidence at INEEL. Noncarcinogenic hazardous chemical impacts were estimated using an HI and are presented in Table 5-92. No noncarcinogenic health effects would occur for an HI less than 1, and only at SRS, with an estimated HI of 2 for the MEI from ingestion of mercury in groundwater, would any noncarcinogenic impacts be expected.

Table 5-91
Maximum Lifetime MEI and Population Impacts
for Seven Major Generator-Storage Sites Under No Action Alternative 2

	Radiological Impacts		Chemical Carcinogenic Impacts	
Major Sites	**Lifetime LCF [a]**	**Dominant Pathway**	**Lifetime Cancer Incidence**	**Dominant Pathway**
MEI Impacts				
Hanford	1E-04	Inhalation	2E-06	Groundwater Ingestion
INEEL	4E-03	Groundwater Ingestion	5E-03	Groundwater Ingestion
LANL	5E-05	Inhalation	1E-07	Resuspended Soil Ingestion
LLNL	7E-06	Inhalation	5E-06	Groundwater Ingestion
ORNL	3E-06	Groundwater Ingestion	6E-07	Groundwater Ingestion
RFETS	2E-03	Inhalation	3E-07	Groundwater Ingestion
SRS	7E-04	Groundwater Ingestion	4E-04	Groundwater Ingestion
Population Impacts				
Hanford	7E-04	Resuspended Soil Ingestion	2E-06	Surface Water Ingestion
INEEL	0.07	Inhalation	3E-06	Resuspended Soil Ingestion
LANL	0.08	Inhalation	2E-04	Resuspended Soil Ingestion
LLNL	0.02	Inhalation	3E-07	Resuspended Soil Ingestion
ORNL	4E-05	Inhalation	3E-07	Surface Water Ingestion
RFETS	7.1	Inhalation	3E-04	Resuspended Soil Ingestion
SRS	0.09	Inhalation	6E-05	Surface Water Ingestion

[a] Probability of an LCF for the MEIs; number of LCFs for the populations.

Table 5-92
Noncarcinogenic Hazardous Chemical Impacts to MEIs
at Seven Major Generator-Storage Sites for No Action Alternative 2

Major Generator/Storage Sites	HI [a]	Key Chemical	Dominant Pathway
Hanford	0.2	Mercury	Groundwater Ingestion
INEEL	0.3	Carbon Tetrachloride	Groundwater Ingestion
LANL	2E-03	Mercury	Resuspended Soil Ingestion
LLNL	5E-04	Carbon Tetrachloride	Resuspended Soil Ingestion
ORNL	3E-04	Mercury	Groundwater Ingestion
RFETS	6E-05	Lead	Inhalation
SRS	1.5	Mercury	Groundwater Ingestion

[a] No noncarcinogenic impacts would occur for an HI less than 1.

Impacts to populations for the maximum 70-year lifetime over 10,000 years of environmental release of contaminants are also presented in Table 5-91 for the seven major generator-storage sites. Exposures from the air and groundwater to surface water pathways were included.

Radiological impacts to populations would range from 4×10^{-5} LCFs at ORNL to 7.1 LCFs at RFETS. Carcinogenic hazardous chemical impacts would range from 1×10^{-7} cancers at LLNL to 3×10^{-4} cancers at RFETS.

The aggregate number of LCFs that could occur in off-site populations around the seven sites over 10,000 years (approximately 142 70-year lifetimes) from release of the No Action Alternative 2 inventory was estimated. The aggregate number of LCFs for all sites was estimated to be 794 LCFs, with 98 percent of the estimated LCFs (781) occurring in the population around RFETS. In addition to the impact from release of the No Action Alternative 2 inventory, the number of aggregate LCFs at the seven sites was estimated for the Additional Inventory of Action Alternative 1 (see Tables 3-2 and 3-3) which would also remain in place at the sites under the No Action Alternative 2. An additional 13 aggregate LCFs were estimated to occur from release of the Additional Inventory. Release of the combined inventories would result in about 800 LCFs. Estimates of site-specific and total aggregate LCFs are presented in Table 5-93. The aggregate hazardous chemical impact over 10,000 years was estimated to be about 0.002 cancers. These

Table 5-93
Aggregate LCFs over 10,000 Years for Seven Major Generator-Storage Sites
After Loss of Institutional Control for No Action Alternative 2

Site	Aggregate LCFs from Basic Inventory	Aggregate LCFs from Additional Inventory	Aggregate LCFs from Combined Inventory
Hanford	0.01	0.01	0.02
INEEL	3.8	7.7	11.4
LANL	8.5	5.6	14.1
LLNL	0.4	0	0.4
ORNL	6E-04	3E-04	9E-04
RFETS	781	0	781
SRS	0.3	0.1	0.4
Total	**794**	**13**	**807**

impacts were estimated based on current population distributions. These distributions may change substantially, creating the potential for significant increases over these estimates of aggregate LCFs.

5.7 RETRIEVAL AND RECOVERY

Waste "retrieval," as defined by the WIPP LWA, is "the removal of TRU waste and the container in which it has been retained, and any material contaminated by such waste from the underground repository at WIPP." For the purposes of analyses, SEIS-II distinguishes between waste "retrieval" and waste "recovery." Retrieval is the removal of intact (unbreached) waste containers. Retrieval is presumed to occur prior to the closure of WIPP before salt reconsolidation (rock creep) begins to crush CH-TRU waste drums and standard waste boxes or RH-TRU waste canisters. Waste "recovery" assumes that the waste containers would be breached through the process of salt reconsolidation and would include the removal of waste, waste containers, and any material contaminated by such waste. The analysis of waste removal at some future time is based on the following general assumptions: (1) the reason for removing the waste would be known; (2) the transportation mode, destination, and end use would be known; (3) waste removal would be based on future available technologies and future regulations.

The consequence analysis presented in the following subsections is intended to bound the impacts that could occur in the unlikely event that waste would need to be removed from the WIPP repository. If one or more panels of waste were removed after the panels had been closed but prior to repository closure, the impacts of waste removal would be proportional to the number of panel equivalents removed. In general, worker impacts would increase in proportion to the number of waste containers that have been breached.

5.7.1 Waste Retrieval

The retrieval of waste from WIPP prior to closure would conceptually be the reverse of the initial disposal. Because the facility would not have been closed, it was assumed that (1) the surface facilities, equipment, and shafts would be intact and operational, (2) access to the waste would be available via the access tunnels, (3) panel rooms would not have collapsed, and (4) the waste containers would be unbreached and intact. For this analysis, it was assumed that one panel of waste (17,560 cubic meters [620,000 cubic feet]) would be removed. This is equal to 10 percent of the Basic Inventory, the total of which is proposed for disposal in ten panel equivalents. If more than one panel were retrieved, the impacts would be proportional to the number of panel equivalents retrieved.

5.7.1.1 Operational Impacts of Waste Retrieval

Operational impacts of retrieving CH-TRU and RH-TRU waste from one panel-equivalent would be essentially the same as the impacts of emplacing that waste. Approximately 40 workers would be involved with removing the waste from the panel on a daily basis for a period of 2 years. The worker-population dose for this operation would not exceed 80 person-rem, based on WIPP administrative limits of 1 rem total effective dose equivalent (TEDE) per year, and would probably be much smaller. The number of LCFs in the worker population from this exposure would be about 0.03. The potential of cancer incidence from exposure to hazardous chemicals would be smaller, on the order of 5×10^{-6}. No noncarcinogenic effects from exposure to hazardous chemicals would be expected.

Impacts to the public and to noninvolved workers would be expected to be smaller, by at least an order of magnitude, than the values for WIPP operations under the Proposed Action (Tables 5-11 and 5-12). The estimated number of LCFs in the general population from radiation exposure was 3×10^{-5}, while cancer incidence from hazardous chemical exposure was about 2×10^{-6}. The MEI would have a 3×10^{-8} probability of an LCF from radiation exposure and about a 3×10^{-9} probability of a cancer incidence. The noninvolved worker population would have an estimated 4×10^{-5} LCF from radiation exposure and cancer incidence from hazardous chemical exposure would be about 1×10^{-5}. The maximally exposed noninvolved worker would have a 5×10^{-7} probability of an LCF from radiation exposure, and about a 1×10^{-8} probability of a cancer incidence. No noncarcinogenic health effects would be expected, with HIs not exceeding those under the Proposed Action and no larger than 6×10^{-5}.

5.7.1.2 Transportation Impacts of Waste Retrieval

Transportation impacts from the retrieval of one panel of waste would be the same for transporting the waste to WIPP for disposal. The impact of transporting waste is primarily based on the number of shipments required and the shipping destination distances. Because the amount of waste would be the same as originally disposed of, and the waste would be shipped back to the origination site, the number of shipments and shipping destinations would be the same, making the transportation impact the same. The estimated impacts of transporting one panel of TRU waste removed from WIPP to the waste origination site would be less than one vehicle-related fatality and less than one nonoccupational LCF (see Appendix E).

5.7.2 Waste Recovery

Recovery of waste from WIPP could occur during operations or after closure. Recovery after closure would require the sinking of new shafts and the excavation of new drifts. For this analysis it was assumed that standard mining techniques would be used until excessive contamination or radiation fields are encountered. In contaminated areas, currently available remote-controlled excavation equipment or equipment modified with off-the-shelf systems may be used. Where practical, waste removal operations and support operations, such as radiation and air quality monitoring, and geotechnical surveying, would be performed remotely. Contaminated and uncontaminated equipment and materials would be segregated, and maintenance operations would use separate ventilation systems.

Excavated waste materials would be placed in appropriately designed waste containers. The surfaces of the containers would be decontaminated, if necessary, prior to being transported aboveground. Aboveground facilities would include a control center where all remote operations would be coordinated and a decontamination area where waste containers would undergo additional decontamination if necessary. The waste containers would be staged aboveground for transportation to a pre-determined location or end use. A control center in the underground would provide the interface between the aboveground control center and underground operational activities.

The excavation and waste removal operations would be designed to reduce the amount of contamination and radiation exposure, and to allow limited human access for assessments, equipment retrieval, and equipment repairs. Operations would be designed to reduce direct human involvement to the extent practicable. Radiological work would be performed using standard industry practices and approved procedures.

Standard mining equipment would be used to sink the shafts and to excavate the drifts and support rooms. After the underground support areas have been completed, the waste would be removed. Reduced scale mining equipment would be used to remove the waste. A reduction in scale would enable the vehicles and supporting equipment to be remotely controlled and to handle waste materials not usually associated with mining activities. The CH-TRU and RH-TRU waste would be retrieved in separate operations. The RH-TRU waste would be removed as intact as possible. Because the RH-TRU waste poses a greater external radiation hazard, RH-TRU waste removal activities would require more rigorous measures to limit personnel exposure.

It is anticipated that a long time period would be needed to complete the removal of waste, but no time limit would be specified. The removal approach would minimize the overall hazards.

After the waste has been removed from the repository, the facility would be decommissioned in accordance with the regulatory requirements applicable at that time. Closure may include partial backfilling of the repository and support areas. The entire repository would not be backfilled, however. The intent would be to dispose of uncontaminated excavated salt and other materials removed from the underground during the initial mining operations. The shafts may be sealed; surface facilities would be decontaminated and decommissioned. All decontamination waste could be packaged and shipped in the same fashion as the waste removed.

The analysis for the recovery of waste after closure was based on the assumptions that (1) the repository has been closed for a period of time sufficient for total encapsulation of the waste and reconsolidation of the salt, (2) waste containers have been breached, and (3) waste characterization requirements and the process/equipment that meet these requirements are known and are based on regulations current at the time of removal.

A volume of 400,000 cubic meters (14 million cubic feet) of CH-TRU and RH-TRU waste was assumed to have been disposed of. This volume, which is the volume of waste disposed of under Action Alternative 3 (the maximum under any alternative), would be emplaced in 71 waste panels. To recover the disposed of waste, the materials that would be removed from the repository would include 3,370,000 cubic meters (119 million cubic feet) of contaminated material and 570,000 cubic meters (20 million cubic feet) of uncontaminated material. These volumes include uncontaminated materials from newly excavated repository shafts and access drifts and contaminated materials from the waste panel rooms and drifts, plus an additional 10 percent to include contaminated materials that may have penetrated into the disposal panel or drift floors or walls.

5.7.2.1 Operational Impacts of Waste Recovery

Operational impacts of recovering emplaced CH-TRU and RH-TRU waste from the entire repository 100 years after closure would be substantially greater than the impacts of emplacing the waste. In addition to excavation of waste, containers, and surrounding contaminated salt, there would be substantial effort involved in packaging the material for safe shipment. Packaging of recovered waste and contaminated salt was assumed to take place underground. It was assumed that engineered contamination controls, such as a HEPA-filtered ventilation system typical of DOE facilities that handle radioactive material, would be put into place. DOE believes that such controls would maintain releases and radiation exposures below the current regulatory levels. Therefore, all releases and radiation exposures to the public and workers were assumed to be limited to current regulatory standards, and the MEI would receive no more than 10 mrem per year, the

NESHAP limit for radionuclides in 40 CFR Part 61. Workers would be subject to the WIPP administrative dose limit of 1 rem per year.

The number of workers required for excavation and packaging activities was estimated to be about 100. The time period needed to remove the waste was estimated to be about the same as that required for emplacement, about 200 years, based on 5 years to excavate and package each panel containing CH-TRU and RH-TRU waste, and 2 years to excavate and package each panel containing only RH-TRU waste. Assuming a 35-year work period per worker, the accumulated worker-population dose over the entire 200-year recovery period would be 20,000 person-rem. The maximum accumulated LCFs in the involved worker population would be about 8. The accumulated potential of cancer incidence from exposure to hazardous chemicals would be smaller, on the order of 1×10^{-3}. No noncarcinogenic effects from exposure to hazardous chemicals would be expected.

The impact to the MEI receiving 10 mrem per year (the NESHAP radionuclide limit) would be approximately 1,000 times the calculated impact to the MEI from WIPP disposal operations under Action Alternative 3 (Tables 5-64 and 5-65). This ratio was used to estimate the potential impacts to the public and noninvolved workers from waste recovery, adjusting Action Alternative 3 impacts upward by a factor of 1,000. The estimated number of LCFs in the general population from radiation exposure would be 0.3, while cancer incidence from hazardous chemical exposure would be 0.02. The MEI would have a 3×10^{-4} probability of an LCF from radiation exposure, and about a 1×10^{-5} probability of a cancer incidence from exposure to hazardous chemicals. The noninvolved worker population would have an estimated 0.5 LCF from radiation exposure, and cancer incidence from hazardous chemical exposure would be about 0.09. The maximally exposed noninvolved worker would have a 3×10^{-4} probability of an LCF from radiation exposure, and about a 5×10^{-5} probability of a cancer incidence. No noncarcinogenic health effects would be expected, with the HIs not exceeding those under Action Alternative 3 and no larger than 1×10^{-3}.

5.7.2.2 Transportation Impacts of Waste Recovery

The transportation impacts of recovering the waste would be substantially greater than for its disposal because there would be a much greater volume of recovered waste (3.4 million cubic meters [121 million cubic feet]). It is assumed that the recovered waste would be transported to the treatment sites using the transportation consolidation described for Action Alternative 3. Because contaminated salt would be treated as waste, each generator site would receive more waste than it originally shipped for disposal.

The large volume of contaminated salt would increase the number of shipments by a factor of 8.5, increasing the transportation impact by approximately the same factor. This impact estimate is conservative because, in the time between disposal and recovery, the radionuclides with short half-lives would have decayed sufficiently to reduce accident-free radiological impacts to a large extent. Also, because much of the recovered waste would have a large salt component, the salt would provide shielding for the radioactive component. This self-shielding effect would further reduce accident-free impacts. The bounding accident impacts, however, would be about the same as that calculated for Action Alternative 3 (3 LCFs for CH-TRU waste average radionuclide concentration scenario) because the half-life of the alpha emitting radionuclides, which contribute most to internal dose, have relatively long half-lives. After 100 years, these radionuclides would not have decayed sufficiently enough to substantially reduce impacts. The maximum radiological populations impacts calculated to occur from nonoccupational accident-free exposures is estimated

to be the same as Action Alternative 3 (15 LCFs). Vehicle-related traffic fatalities would increase to 185 due to a proportional increase in waste and transportation miles (see the related discussion in Appendix E for complete estimated transportation impacts).

5.8 ENVIRONMENTAL JUSTICE

DOE is in the process of developing environmental justice guidance, pursuant to Executive Order 12898. This guidance will be finalized after stakeholder comments, concerns, and opinions are received, reviewed, and incorporated, as appropriate.[1] The approach taken in this SEIS-II analysis may depart somewhat from the guidance that is eventually issued or from the approach taken in other documents. Information concerning minority populations for New Mexico as a whole is included in this section in response to public comments.

For purposes of this analysis, a high and adverse human health or environmental impact is a significant deleterious human health or environmental impact. A disproportionate impact to a minority or low-income population is one that substantially exceeds, or is likely to exceed, the same type of impact in the larger community. A disproportionately high and adverse human health or environmental impact would occur when the adverse human health or environmental effects are significant, and the risk or rate to a minority or low-income population from exposure (or multiple exposures) to the environmental or health hazard(s) substantially exceeds, or is likely to exceed, the risk or rate to the general population.

The SEIS-II environmental justice analysis for the vicinity of WIPP addresses the potential for disproportionately high and adverse human health or environmental effects on minority and low-income populations within an 80-kilometer (50-mile) area of the WIPP site. The shaded areas in Figures 4-11 and 4-12 show the percentage of minority populations and low-income populations, respectively, in census blocks around the WIPP site. Minorities comprise about 36.8 percent of the population in the 80-kilometer (50-mile) area around WIPP, and low-income individuals about 21.5 percent of this population.

Approximately 38 percent of New Mexico's population is Hispanic. Approximately 9 percent of New Mexico's population is Native American.

The populations within an 80-kilometer (50-mile) area of the non-WIPP treatment sites are described in Chapter 4 of SEIS-II. SEIS-II also incorporates by reference the maps of the census tracts containing greater than 50 percent minority and low-income populations within the 80-kilometer (50-mile) area of treatment sites that are included in Appendix C of the WM PEIS. Of note for environmental justice assessments are LANL and SRS, where minorities constitute greater than 55 percent and 35 percent, respectively, of the total populations within the 80-kilometer (50-mile) area.

For treatment, potentially high and adverse human health effects could occur during normal, accident-free treatment operations at some treatment sites as a result of TRU waste management activities under the three Action Alternative 2 subalternatives. Several areas in the vicinity of WIPP contain a greater percentage of minorities than some other areas within the 80-kilometer (50-mile) area of WIPP and the population of the United States as a whole. It is possible, therefore, that adverse health impacts (estimate of 1 fatality) from routine or accident-free thermal

[1] The Council on Environmental Quality has also developed draft "Guidance for Addressing Environmental Justice Under the National Environmental Policy Act."

treatment of waste at WIPP under Action Alternative 2C would disproportionately affect the minority populations in the vicinity of WIPP. The prevailing winds at both SRS and LANL would direct treatment releases away from the concentrations of minority and low-income populations that exist around those sites.

At all treatment sites, treatment accidents would be unlikely so that accidents would not be expected to impact off-site populations; also, the impacts from treatment accidents would depend on meteorological conditions at the time of the accident. For these reasons, it is not likely that adverse environmental or human health impacts would disproportionately affect the minority or low-income populations at any of the treatment sites.

Potentially high and adverse impacts as defined above may occur as a result of waste transportation activities. Because all TRU waste would travel through New Mexico, residents of the State could be affected by transportation activities, although impacts would be spread throughout the transportation corridors. Routine truck transportation could cause between 3 (under the Proposed Action) and 15 (under Action Alternative 3) public fatalities over the life of the project from radiation exposure. These impacts are likely to be much lower because of conservative assumptions used in the analysis (e.g., assuming more stops than would actually occur). For the Proposed Action, less than 5 percent of the radiological impacts would be to those living along the highways. The ethnic and income distribution of travelers and workers at rest stops, where the impacts would primarily occur, would vary over time and by location. Thus, potential high and adverse impacts from routine transportation would not be likely to disproportionately affect minority or low-income populations.

Under the action alternatives, there could be from 5 (using truck transportation under the Proposed Action) to 264 fatalities (using dedicated rail under Action Alternative 3) from traumatic injuries sustained in accidents involving transportation vehicles. For truck transportation, accidents not involving a release of radioactivity are most likely to affect those traveling along the same route; for rail transportation, such accidents are most likely to affect those traveling near railroad crossings. Accidents would be random events that could occur on any segment of the transportation routes. Whether such travelers are minorities or low-income individuals cannot be predicted. Therefore, any high and adverse impacts from transportation accidents are not likely to disproportionately affect minority or low-income populations.

Severe transportation accidents that breach the transport package could result in up to 16 LCFs (from release of radioactive material) under any of the action alternatives. Accidents involving a release of radioactive material are most likely to affect residents and travelers along the transportation corridors, although the probability that an accident would involve a release of radioactive material is low (1.5×10^{-5} per accident). As noted above, accidents would be random events that could occur on any segment of the transportation routes. Whether the affected people would be minorities or low-income individuals cannot be predicted. Therefore, any high and adverse impacts from transportation accidents are not likely to disproportionately affect minority or low-income populations.

For disposal at WIPP, normal accident-free operations would not cause significant adverse human health or environmental impacts, and thus there would be no such impacts that could disproportionately affect minority or low-income populations. For disposal accidents, the most severe accident (the waste hoist failure) could cause up to 4 public fatalities for the Proposed Action and up to 24 fatalities for Action Alternative 3. However, the annual probability of this

accident is 4.5×10^{-7}. Therefore, although possible, disproportionately high and adverse effects on minority or low-income populations would not be expected.

5.9 CUMULATIVE IMPACTS

This section focuses on the cumulative impacts that could result once the incremental impacts of the SEIS-II Proposed Action (its Preferred Alternative) and action alternatives are added to the impacts of other past, present, and reasonably foreseeable future actions. Throughout this section, the cumulative impacts discussion in the Final WM PEIS is incorporated by reference. This assessment of cumulative impacts also considers a number of other NEPA documents, including those listed in Table 5-94.

5.9.1 Cumulative Impacts in the Vicinity of WIPP

The WIPP site was withdrawn in the LWA for the purpose of TRU waste disposal and related activities, and DOE has no plans to dispose of other types of waste at WIPP nor to conduct any other type of activity there.

Future mining and drilling to extract mineral resources known to exist within the Land Withdrawal Boundary in the vicinity of WIPP would be prohibited by the LWA in the foreseeable future. Activity on two existing leases near the WIPP site would be allowed only if EPA found that such activity would not affect WIPP performance; otherwise, DOE would acquire those leases. The SEIS-II long-term performance assessment (presented both in this chapter and in Appendix H) takes into account the potential impacts of mining and drilling activities that might result after WIPP closure and the period of active institutional control.

DOE is also exploring the possibility of obtaining a Toxic Substances Control Act (TSCA) permit to dispose of the small amount (less than 700 cubic meters [25,000 cubic feet] as estimated in BIR-3) of PCB-commingled TRU waste without treatment. This waste was included in the CH-TRU waste Additional Inventory and was analyzed in SEIS-II.

DOE may propose to treat low-level alpha mixed waste at INEEL with a thermal process that would reduce the waste volume and concentrate TRU radionuclides. If DOE decides to use such a treatment process at INEEL, all or a portion of the resulting waste form could become CH-TRU waste after treatment. The thermally treated low-level alpha mixed waste would have characteristics similar to the other CH-TRU waste examined in the SEIS-II analyses, and disposal of this waste at WIPP would have impacts similar to the disposal of any other equivalent volume of CH-TRU waste. The volume of this waste is estimated to be about 27,000 cubic meters (930,000 cubic feet), which after treatment would occupy most of the projected unused CH-TRU waste disposal capacity of WIPP. While the CH-TRU waste capacity that was assumed to be emplaced for the SEIS-II Proposed Action (its Preferred Alternative) was adjusted up for the purpose of bounding the analyses to this disposal limit, the results of the analyses for the Proposed Action would have been essentially the same had the treated low-level mixed waste been included in the TRU waste inventory and assumed to take up the additional volume. Likewise, addition of this relatively small volume of treated TRU waste to the waste volumes examined under any of the SEIS-II action alternatives would not substantially affect the environmental impacts of disposal.

Table 5-94
Documents Describing Other Activities Included in the Cumulative Impact Analysis

Title	Applicable Sites
Final Environmental Impact Statement, Defense Waste Processing Facility	SRS
Final Supplemental Environmental Impact Statement, Defense Waste Processing Facility	SRS
Savannah River Site Waste Management Final Environmental Impact Statement	SRS
Final Environmental Impact Statement, Long-Term Management of Liquid High-Level Radioactive Wastes Stored at the Western New York Nuclear Service Center, West Valley	West Valley Demonstration Project
Final Environmental Impact Statement, Management of Spent Nuclear Fuel from the K Basins at the Hanford Site, Richland, Washington	Hanford
Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement	Hanford, INEEL, SRS
Storage and Disposition of Weapons-Usable Fissile Materials, Environmental Impact Statement	Hanford, INEEL, NTS, ORR, Pantex, SRS
Medical Isotopes Production Project: Molybdenum-99 and Related Isotopes Environmental Impact Statement	LANL, SNL
Dual Axis Radiographic Hydrodynamic Test Facility, Final Environmental Impact Statement	LANL
Final Environmental Impact Statement for the Tank Waste Remediation System	Hanford
Plutonium Finishing Plant Stabilization Final Environmental Impact Statement	Hanford
Programmatic Environmental Impact Statement for Stockpile Stewardship and Management	LLNL, LANL, NTS, ORR, Pantex, SRS
The Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada	NTS
Draft Environmental Impact Statement for Completion of the West Valley Demonstration Project and Closure or Long-Term Management of Facilities at the Western New York Nuclear Services Center	WVDP
Final F-Canyon Plutonium Solutions Environmental Impact Statement	SRS
Proposed Interim Storage of Enriched Uranium Above the Maximum Historical Storage Level at the Y-12 Plant, Oak Ridge, Tennessee	ORR
Final Programmatic Environmental Impact Statement for Tritium Supply and Recycling	INEEL, NTS, ORR, Pantex, SRS
Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada	NTS
Savannah River Site Waste Management Final Environmental Impact Statement	SRS
Final Environmental Impact Statement for Continued Operations of Lawrence Livermore National Laboratory and Sandia National Laboratories	LLNL, SNL-CA
Disposition of Surplus Highly Enriched Uranium, Environmental Impact Statement	ORR, SRS
Final Programmatic Environmental Impact Statement for Tritium Supply and Recycling	SRS
Environmental Impact Statement for the Continued Operation of the Pantex Plant and Associated Storage of Nuclear Weapon Components	Pantex
Draft Hanford Remedial Action Environmental Impact Statement and Comprehensive Land Use Plan	Hanford
Final Environmental Impact Statement on the Disposal of Decommissioned, Defueled Cruiser, Ohio Class and Los Angeles Class Naval Nuclear Plants	Hanford
Nonnuclear Consolidation Environmental Assessment	LANL, ORR, RFETS, SNL, SRS
Proposed 7-GeV Advanced Photon Source Environmental Assessment	ANL-E
Environmental Assessment of the Environmental Restoration Project at Sandia National Laboratories	SNL

DOE also is considering whether to classify some stabilized plutonium residues (with less than 20 percent plutonium by weight) as TRU waste. These residues are not usable for weapons and are stored primarily at Hanford, INEEL, LANL, LLNL, RFETS, and SRS. Residues with less than 20 percent plutonium by weight at RFETS were reported as TRU waste volumes in BIR-3, and the impacts of disposal of the RFETS residues were examined as part of the SEIS-II Proposed Action and the action alternatives. The Department will prepare additional site-specific NEPA analyses, as appropriate, concerning management and stabilization of the residues before decisions are made concerning disposal at WIPP.

Other DOE decisions may result in generation of TRU waste that could ultimately be destined for WIPP. The ROD for the *Final Programmatic Environmental Impact Statement for Stockpile Stewardship and Management* (DOE 1996e) has little impact on TRU waste generation potential. The ROD for the *Storage and Disposition of Weapons-Usable Fissile Materials Final Programmatic Environmental Impact Statement* (DOE 1996h) may potentially have a greater impact on TRU waste generation. The Department decided to pursue a dual strategy for disposing of excess weapons-usable plutonium that would immobilize some (and potentially all) of the inventory in a glass or ceramic material and allow the burning of some of the surplus plutonium as mixed oxide fuel in existing reactors, depending upon subsequent decisions. The Department is preparing a *Surplus Plutonium Disposition Environmental Impact Statement* (Notice Of Intent, May 22, 1997, 62 FR 28009). The disposition of surplus weapons-usable plutonium (a fissile material) could produce approximately 4,500 cubic meters (158,000 cubic feet) to 7,000 cubic meters (245,000 cubic feet) of additional TRU waste for disposal at WIPP.

5.9.2 Cumulative Transportation Impacts

The cumulative effects of transporting low-level, low-level mixed, high-level, hazardous, and TRU wastes are presented in the Final WM PEIS (DOE 1997). For the following discussion, the information in the Final WM PEIS, which examined 20 years of transportation for all waste types except high-level waste (for which 40 years of transportation was analyzed), has been incorporated and supplemented by information in SEIS-II (which examined 35 years of transportation).

The totals in the Final WM PEIS show that transporting all waste types between generator, treatment, storage, and disposal sites by truck would result in an aggregate total of between 12 fatalities (under one of the regionalized alternatives for TRU waste considered in the WM PEIS) and 69 fatalities (under the decentralized alternative for TRU waste considered in the WM PEIS). The total for the SEIS-II Proposed Action (over 35 years) would increase to about 15 fatalities for transportation of TRU waste by truck to WIPP. Approximately 6 of these 15 fatalities would result from radiation exposure, with the remainder due to injuries induced by physical trauma.

Cumulatively, transportation of all waste types by rail would result in 11 fatalities (for SEIS-II Action Alternative 1) to 15 fatalities (for SEIS-II Action Alternative 3). Rail transportation impacts were not examined for the SEIS-II Proposed Action. Transportation by rail would result in a reduction of both radiological and physical trauma impacts as compared to truck transportation.

If the potential impacts from other DOE and non-DOE transportation activities are included, approximately 175 radiation-related LCFs may occur in the general population and an additional 140 radiation-related LCFs may occur among workers from past, present, and reasonably foreseeable transportation activities (including transportation to WIPP) (DOE 1997).

5.9.3 Cumulative Impacts at Treatment Sites

The Final WM PEIS (DOE 1997) examined the impacts of storage and treatment of TRU waste at major storage or treatment sites and found the potential for TRU waste management activities to affect health or to exceed applicable air quality standards. It also found cumulative impacts as a result of combined activities at those sites. These cumulative impacts are presented in the Final WM PEIS.

The Final WM PEIS did not examine cumulative impacts at Mound. However, the bounding analysis in the *Environmental Assessment for Commercialization of the Mound Plant* (DOE 1994c) does not project the generation of any TRU waste or any impacts associated with TRU waste at Mound.

The cumulative impacts of the SEIS-II Proposed Action (Preferred Alternative) and Action Alternative 1 during the 10 years analyzed by the Final WM PEIS would be virtually identical to those of the Final WM PEIS preferred alternative. Those impacts are presented below. For SEIS-II Action Alternatives 2 and 3, treatment was assumed to begin after the 10-year period examined in the Final WM PEIS, because it would take an estimated 12 years to design, build, and obtain permits for the treatment facilities. Treatment, therefore, would not begin until after the 10-year period assessed in the Final WM PEIS.

For the cumulative impacts for time periods beyond the 10-year period, as examined below, the impacts from TRU waste (as noted in this chapter for a 35-year period) would be added to those impacts from other actions that are foreseeable or ongoing at that time. DOE has not attempted to predict the cumulative impacts beyond 10 years, because many of the actions that might contribute to those impacts are not reasonably foreseeable at this time. The following discussion focuses on human health impacts and presents the impacts of the Final WM PEIS preferred alternative. Other cumulative impacts due to construction and operation of storage and treatment facilities would also be similar or identical to those presented in the Final WM PEIS.

Hanford Site

No off-site public radiation cancer fatalities (0.14 LCF) and 11 worker radiation fatalities (11.1 LCFs) would result from ongoing operations, waste management activities, and other reasonably foreseeable future actions at Hanford.

Idaho National Engineering and Environmental Laboratory

No off-site public radiation cancer fatalities (0 LCF) and 2 worker radiation fatalities (2.04 LCFs) would result from ongoing operations, waste management activities, and other reasonably foreseeable future actions at INEEL.

Los Alamos National Laboratory

No off-site public radiation cancer fatalities (0 LCF) and 2 worker radiation fatalities (2.11 LCFs) would result from ongoing operations, waste management activities, and other reasonably foreseeable future actions at LANL.

Nevada Test Site

No off-site public radiation cancer fatalities (0 LCF) and 3 worker radiation fatalities (2.87 LCFs) would result from ongoing operations, waste management activities, and other reasonably foreseeable future actions at NTS.

Oak Ridge National Laboratory

No off-site public radiation cancer fatalities (0.23 LCF) and 2 worker radiation fatalities (1.6 LCF) would result from ongoing operations, waste management activities, and other reasonably foreseeable future actions at ORNL.

Rocky Flats Environmental Technology Site

No off-site public radiation cancer fatalities (0 LCF) and no worker radiation fatalities (0 LCF) would result from ongoing operations, waste management activities, and other reasonably foreseeable future actions at RFETS.

Savannah River Site

Approximately 1 off-site public radiation cancer fatality (1.48 LCF) and 8 worker radiation fatalities (8.0 LCF) would result from ongoing operations, waste management activities, and other reasonably foreseeable future actions at SRS.

Lawrence Livermore National Laboratory

No off-site public radiation cancer fatalities (0.18 LCF) and no worker radiation fatalities (0.16 LCF) would result from ongoing operations, waste management activities, and other reasonably foreseeable future actions at LLNL.

Argonne National Laboratory – East

No off-site public radiation cancer fatalities (0 LCF) and no worker fatalities (0 LCF) would result from ongoing operations, waste management activities, and other reasonably foreseeable future actions at ANL-E.

5.10 MITIGATION MEASURES

Analyses of potential environmental impacts in SEIS-II did not identify the need for any additional mitigation measures above those described in the FEIS (DOE 1980) and SEIS-I (DOE 1990). Most of the previously identified mitigation commitments have been fulfilled at WIPP for construction and predisposal phases or were intended to apply to underground tests at WIPP using TRU waste that never took place. DOE will reevaluate ongoing mitigation measures from the FEIS and SEIS-I and mitigation proposals for the disposal phase in light of SEIS-II analyses. Most of the following mitigation measures are included as part of each alternative and would be implemented by DOE to reduce potential impacts. DOE will specify the mitigation measures to be implemented for the action selected in the Record of Decision.

Air quality impacts may be mitigated by activities to reduce generation of criteria pollutants at WIPP, including the use of proper, low-contaminant fuels; paving heavily trafficked areas; and

spraying water on dusty roads to minimize fugitive dust emissions. Similar measures may also be taken during decommissioning to minimize air quality impacts. The HEPA filtration systems are already in place and can be used to mitigate any potential releases of radionuclides from the WIPP waste handling facilities. The use of radiation monitors to activate HEPA filtration of underground exhaust air (a mitigation commitment made in SEIS-I) may be reevaluated.

Biological resource impacts would be mitigated by avoiding unnecessary damage to vegetation, wildlife, and soil by controlling traffic, minimizing the areas of disturbance, controlling runoff, and cleaning up spills. Any temporary facilities such as haul roads, stockpiles, and work areas may be restored by regarding, reseeding, and fencing as activities requiring these facilities are completed. Environmental monitoring is ongoing and could continue, as necessary, to provide early warning of affects on the biological environment so that specific mitigative measures could be developed and implemented. DOE plans to return decommissioned land used in the operation of WIPP to a stable ecological condition and maintain or enhance the ecological condition of wildlife habitat within the Land Withdrawal Area (DOE 1996a). Disturbed areas would be restored as soon as possible after decommissioning, using methods of soil replacement and revegetation conducive to soil stabilization and wildlife needs.

Cultural resource impacts could be mitigated by performing additional surveys of areas that could be disturbed by surface activities, including those during decommissioning. DOE would attempt to avoid potential cultural and historic sites to the extent possible; if avoidance is not possible, specific mitigation measures would likely be developed in consultation with the State Historic Preservation Office, the Advisory Council on Historic Preservation, and the BLM.

Some socioeconomic impact was mitigated when DOE eliminated the former “Control Zone IV” in the 1980's, releasing the area of this zone that was outside the current Land Withdrawal Boundary and making available an estimated 50 million tons of potash for mining and opening the area for oil and gas recovery. In the event that either of the no action alternatives were selected, DOE may mitigate impacts to the regional economy by staging worker layoffs over the course of the decommissioning period. DOE could also assist laid-off workers by offering such services as worker training and reeducation programs, and providing relocation services for finding jobs elsewhere in the DOE complex.

Transportation impacts would be mitigated in a variety of ways in addition to using approved routes and transportation packages. Transportation routes can be selected to meet federal and state regulations. Trucks (and rail cars) transporting TRU waste would be inspected and maintained on a regular basis. Drivers would be required to meet strict selection and training criteria. The TRANSCOM system would be used to monitor truck movement at all times when transporting waste to WIPP. Extensive emergency response capability exists and would be maintained at DOE, the trucking contractor, and in communities along the transportation routes to respond in the event of an accident. In addition, DOE will consider maintaining spill control equipment to protect the environment from fuel spills, should a transportation accident occur.

Human health impacts to the public and noninvolved worker may be mitigated by using HEPA filtration systems to reduce potential releases of radionuclides or heavy metals from the WIPP waste handling facilities. Worker safety programs are currently in place at WIPP and could continue, with particular emphasis on the physical hazards of underground operations. Mitigation measures for potential radiological impacts to involved workers include adhering to the ALARA philosophy, area and personnel monitoring, and using shielding and remote-handling equipment

when handling high dose rate waste containers. Panel seals would be constructed to reduce operational exposures to VOCs emanating from emplaced waste.

The long-term performance of the repository could be enhanced by taking mitigation measures that include emplacing a chemical backfill with waste in the repository and using plugs and seals in the repository panels, access drifts, and shafts. The performance assessment calculations assumed the use of these mitigation measures. To protect the repository from inadvertent intrusion, hydrocarbon drilling and potash mining would continue to be limited by the BLM and DOE.

The need for specific mitigation measures at the treatment sites would be determined in NEPA reviews performed for the construction and operation of treatment facilities. For example, mitigation of human health impacts from atmospheric releases of radionuclides during treatment operations would be evaluated where treatment impacts warrant such mitigation.

5.11 SHORT-TERM USES AND LONG-TERM PRODUCTIVITY

The LWA prohibits the extraction of mineral and hydrocarbon resources from the 41-square-kilometer (16-square-mile) Land Withdrawal Area during the period of WIPP disposal operations and for perpetuity. After decommissioning and permanent marking, the aboveground area of the WIPP site would be restored by contouring, grading, seeding, and other methods to return it to its natural condition.

5.12 IRREVERSIBLE OR IRRETRIEVABLE COMMITMENT OF RESOURCES

The irreversible and irretrievable commitments of resources associated with the operation of WIPP have not changed substantially from those presented in Section 9 of the FEIS and Section 11 of SEIS-I. Land use for the salt storage pile is currently planned as 12 hectares (30 acres) rather than 24 hectares (60 acres). Although this area would be remediated when the WIPP site is closed, residual salt would probably make growth of any but salt-tolerant species unlikely. Retrieval or recovery activities, discussed in Section 5.7, would probably result in additional use of resources. Retrieval usage would probably equal normal operating uses for the period these activities were under way, while recovery activities would probably be greater than normal operating usage.

Use of diesel fuel for transportation of waste would be more than estimated previously. The FEIS estimate was about 380 cubic meters (100,000 gallons) per year, or about 9,460 cubic meters (2.5 million gallons) for the original WIPP operating period of 25 years. While annual fuel consumption would not be greatly different from the FEIS estimates, total fuel consumption would be 2 to 5 times higher under the Proposed Action.

5.13 CHANGES DUE TO OTHER TRU WASTE VOLUME ESTIMATES

Since the completion of the analyses in the Draft SEIS-II, DOE has continued to update the estimates of stored and to-be-generated TRU waste volumes at the various generator sites. In particular, the *National Transuranic Waste Management Plan* includes updated estimates of the stored and projected volumes of TRU waste at the generator sites. SEIS-II analyses are based on the TRU waste volumes published in BIR-3, although the updated *National Transuranic Waste Management Plan* estimates and associated impacts are also presented in SEIS-II (see Appendix J).

Overall, the *National Transuranic Waste Management Plan* has 5,662 cubic meters (199,951 cubic feet) more CH-TRU waste than the SEIS-II Basic Inventory (before adjustment to the

168,500 cubic meters [5,950,000 cubic feet] allowed by the LWA). This is an increase of 4 percent. *The National Transuranic Waste Management Plan* reports more than 30,000 cubic meters (1,059,000 cubic feet) less of RH-TRU waste than the SEIS-II Basic Inventory. This is a decrease of 86 percent.

The SEIS-II Proposed Action (the Preferred Alternative) presents impacts adjusted to the treatment and disposal of 168,500 cubic meters (5,950,000 cubic feet) of CH-TRU waste (the maximum allowed under the Land Withdrawal Act) and 7,080 cubic meters (250,000 cubic feet) of RH-TRU waste (the maximum allowed under the C & C Agreement with the State of New Mexico). Using the *National Transuranic Waste Management Plan* in the same manner, no change would occur in the impacts for the Proposed Action except for the elimination of impacts related to storage of excess RH-TRU waste. No excess RH-TRU waste, therefore, would be left at ORNL and Hanford.

For the generator-storage sites with significant changes in waste volumes, individual site impacts could vary to a greater extent than indicated by the differences in the total volumes noted above. Under Action Alternatives 1, 2, and 3 and for the individual sites, the following changes would be expected:

- Negligible changes to the impacts would be anticipated in areas of land use and management, biological resources, cultural resources, noise, water resources and infrastructure, long-term performance, or consequences of lag storage accidents. No change would be expected in consequences from treatment accidents or WIPP disposal accidents.

- Changes in the estimated impacts for human health, life-cycle costs (except transportation costs), air quality, industrial safety, and economics would be directly related to changes in CH-TRU and RH-TRU waste volumes. Site impacts would change, as presented in the "percent difference" columns of Table J-1 for CH-TRU waste and Table J-2 for RH-TRU waste. Unlike most other impact areas, CH-TRU waste is a much higher contributor to impacts for involved workers than is RH-TRU waste; therefore, large decreases in RH-TRU waste volumes would have little impact for involved workers. However, at WIPP, large decreases in the amount of RH-TRU waste volumes would reduce the operations time needed for excavation and emplacement, reducing industrial safety and economics impacts.

- Changes in transportation impacts, including costs, are directly related to the number of shipments, which is dependent upon the type of waste treatment. Tables J-4 and J-5 present detailed CH-TRU and RH-TRU waste shipment information for all sites under all alternatives using The National Transuranic Waste Management Plan volumes. Table J-6 (and Table 5-95 presented here) summarize the differences in shipments and the percentages of the total inventories between The National Transuranic Waste Management Plan and the Basic Inventory.

Overall, impacts would be slightly lower using data from *The National Transuranic Waste Management Plan* because, although CH-TRU waste volumes are slightly higher, the RH-TRU waste volumes are markedly lower (except for the impacts to the involved workers, as noted above). The difference is quite marked for transportation impacts because of the reduction of nearly 61,000 shipments of RH-TRU waste under Action Alternative 3 (see Table 5-95).

Table 5-95
Comparison of Shipments Between Alternatives Using
***The National Transuranic Waste Management Plan* and Basic Inventory**

Alternatives	Number of Shipments to WIPP for the Total Inventory			
	NTRUWM Plan	BIR-3	Difference	Percentage of BIR-3 Shipments (NTRUWM/BIR-3)
Proposed Action				
CH-TRU Waste	27,988	29,766 [a]	-1,778	94%
RH-TRU Waste	7,626	7,957	-331	96%
Action Alternative 1				
CH-TRU Waste	41,027	41,003	24	100%
RH-TRU Waste	11,509	62,162	-50,653	19%
Action Alternative 2A				
CH-TRU Waste	43,749	42,775	974	102%
RH-TRU Waste	4,028	21,895	-17,867	18%
Action Alternative 2B				
CH-TRU Waste	43,750	42,774	976	102%
RH-TRU Waste	4,028	21,895	-17,867	18%
Action Alternative 2C				
CH-TRU Waste	43,431	41,206	2,225	105%
RH-TRU Waste	11,507	62,160	-50,653	19%
Action Alternative 3				
CH-TRU Waste	65,922	67,309	-1,387	98%
RH-TRU Waste	13,808	74,606	-60,798	19%

[a] RH-TRU waste volumes are adjusted to the limits of the C&C Agreement. CH-TRU waste volumes are adjusted to reflect the capacity allowed under the LWA taking into account the RH-TRU waste limits of the C&C Agreement.

Changes in volume-dependent impacts (for example, human health impacts) would be expected at some sites. The changes in impacts would be greatest at INEEL, a major generator, treatment, and potential consolidation site under all alternatives, where volume-dependent impacts could increase by about 124 percent. Impacts at RFETS would increase by about 50 percent and at SRS by less than 10 percent. Impacts at Hanford would decrease dramatically: approximately 50 percent from CH-TRU waste and 90 percent from RH-TRU waste. ORNL impacts, mainly from RH-TRU waste, would be about 60 percent lower. Impacts at LANL, the other key generator site, would also decrease by about 15 to 20 percent.

Additional information on how these impacts would change, as well as information on other waste volumes, is presented in Appendix J.

5.14 REFERENCES CITED IN CHAPTER 5

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CHAPTER 6
CONSULTATIONS AND PERMITS

This chapter discusses the results of consultations with various agencies during the preparation of the *Waste Isolation Pilot Plant* (WIPP) *Disposal Phase Final Supplemental Environmental Impact Statement* (SEIS-II). This chapter also lists active, pending and potentially required permits for WIPP.

The National Environmental Policy Act (NEPA) requires that federal, state, and local agencies with jurisdiction or special expertise regarding environmental impacts be consulted and involved in the NEPA process. Agencies involved include those with authority to issue permits, licenses, and other regulatory approvals. Other agencies also include those responsible for protecting significant resources, such as endangered species or wetlands. All such agencies have been sent copies of this SEIS-II document.

The following governmental agencies were consulted.

- New Mexico Forestry Division, New Mexico Energy, Minerals, and Natural Resources Department, 408 Galisteo, Villagra Building, P.O. Box 1948, Santa Fe, NM 87504 (Karen Lightfoot, 505-827-7865)

- U.S. Fish and Wildlife Service, U.S. Department of Interior, New Mexico Ecological Services State Office, 2105 Osuna Road NE, Albuquerque, NM 87113 (Jennifer Fowler-Propst, State Supervisor, 505-761-4525)

- New Mexico Game and Fish Department, P.O. Box 25112, Santa Fe, NM 87504 (Jerry Maracchini, Director, 505-827-9912)

These agencies were contacted in September 1995 in regards to federal- and state-listed endangered, threatened, proposed, and candidate plant species. The agencies responded with species lists (Sivinski and Lightfoot 1995, NMDG&F 1995, and USFWS 1995). Table 4-1 lists the species of special concern for the area surrounding the WIPP site.

Also required by NEPA is a list of permits that are active, pending, or potentially required before disposal can begin at WIPP. Table 6-1, which presents this information, begins on the next page. Other realty components that are constructed, maintained, and utilized by WIPP are referenced in the *WIPP Land Management Plan* (DOE 1996).

Table 6-2 lists DOE orders applicable to this EIS.

Table 6-1
Active, Pending, and Potentially Required Permits and Approvals for the Waste Isolation Pilot Plant Disposal Operations

Granting Agency [a]	Type of Permit or Approval	Status
U.S. Department of the Interior, BLM	Right-of-Way for Water Pipeline	Active
U.S. Department of the Interior, BLM	Right-of-Way for the North Access Road	Active
U.S. Department of the Interior, BLM	Right-of-Way for Railroad	Active
U.S. Department of the Interior, BLM	Right-of-Way for Dosimetry and Aerosol Sampling Sites	Active
U.S. Department of the Interior, BLM	Right-of-Way for Seven Subsidence Monuments	Active
U.S. Department of the Interior, BLM	Right-of-Way for Aerosol Sampling Site	Active
U.S. Department of the Interior, BLM	Right-of-Way for Ten Raptor Nesting Platforms	Active
U.S. Department of the Interior, BLM	Right-of-Way for Survey Monument Installation	Active
U.S. Department of the Interior, BLM	Free Use Permit for Caliche	Active
N.M. Environment Department	Operating Permit for two Backup Generators	Active
N.M. Environment Department	RCRA Part B Permit Application	Pending
N.M. Department of Game and Fish	Individual Banding	Active
N.M. Department of Game and Fish	Master Collecting	Active
N.M. Department of Game and Fish	Concurrence that WIPP disposal activities will have no significant impact on State-listed threatened or endangered species	Active
U.S. Department of the Interior, Fish and Wildlife Service	Master Personal Banding	Active
U.S. Department of the Interior, Fish and Wildlife Service	Concurrence that there are no Federally listed, threatened, proposed, or endangered species at WIPP	Active
U.S. Environmental Protection Agency	Notification of the presence of two Underground Storage Tanks	Active
U.S. Environment Protection Agency	N.M. NPDES Storm Water General Permit	Active
U.S. Environmental Protection Agency	Certification of Compliance with 40 CFR 194	Pending
U.S. Nuclear Regulatory Commission	Certificate of Compliance for the TRUPACT-II	Active
U.S. Nuclear Regulatory Commission	Certificate of Compliance for the RH-72B cask	Pending
N.M. Commissioner of Public Lands	Right-of-Way for High Volume Air Sampler	Active
N.M. State Engineer Office	H-19b1 well, permit to appropriate the underground waters of N.M. for monitoring and characterization	Active
N.M. State Engineer Office	H-19b2 well, permit to appropriate the under waters of N.M. for monitoring and characterization	Active
N.M. State Engineer Office	H-19b3 well, permit to appropriate the underground waters of N.M. for monitoring and characterization	Active
N.M. State Engineer Office	H-19b4 well, permit to appropriate the underground waters of N.M. for monitoring and characterization	Active
N.M. State Engineer Office	H-19b5 well, permit to appropriate the underground waters of N.M. for monitoring and characterization	Active
N.M. State Engineer Office	H-19b6 well, permit to appropriate the underground waters of N.M. for monitoring and characterization	Active
N.M. State Engineer Office	H-19b7 well, permit to appropriate the underground waters of N.M. for monitoring and characterization	Active
N.M. State Engineer Office	WQSP-1 well, permit to appropriate the underground waters of N.M. for monitoring and characterization	Active
N.M. State Engineer Office	WQSP-2 well, permit to appropriate the underground waters of N.M. for monitoring and characterization	Active
N.M. State Engineer Office	WQSP-3 well, permit to appropriate the underground waters of N.M. for monitoring and characterization	Active
N.M. State Engineer Office	WQSP-4 well, permit to appropriate the underground waters of N.M. for monitoring and characterization	Active
N.M. State Engineer Office	WQSP-5 well, permit to appropriate the underground waters of N.M. for monitoring ad characterization	Active
N.M. State Engineer Office	WQSP-6, well, permit to appropriate the underground waters of N.M. for monitoring and characterization	Active
N.M. State Engineer Office	WQSP-7 well, permit to appropriate the underground waters of N.M. for monitoring and characterization	Active
N.M. State Engineer Office	Appropriation: Exhaust Shaft Exploratory Borehole	Active
N.M. State Engineer Office	Exploratory: Exhaust Shaft Exploratory Borehole	Active
N.M. State Engineer Office	H-14 and H-15 Test Wells	Active

[a] U.S. = United States, BLM = Bureau of Land Management, N.M. = New Mexico

Table 6-2
Laws and Regulations Relevant to the WIPP Disposal Phase

Primary Implementing Agency	Law or Regulation	
U.S. Department of Energy Orders	Order 451.1,	National Environmental Policy Act Compliance Program
	Order 5000.3B,	Occurrence Reporting and Processing of Operations Information
	Order 5400.1,	General Environmental Protection Program
	Order 5400.2A,	Environmental Compliance Issue Coordination
	Order 5400.3,	Hazardous and Radioactive Mixed Waste Program
	Order 5400.5,	Radiation Protection of the Public and the Environment
	Order 5480.1B,	Environmental Protection, Safety and Health Protection Program for DOE Operations
	Order 5480.21,	Unreviewed Safety Questions
	Order 5480.22,	Technical Safety Requirement
	Order 5480.23,	Nuclear Safety Analysis Reports
	Order 5480.24,	Nuclear Criticality Safety
	Order 5480.3B,	Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances, and Hazardous Wastes
	Order 5480.4,	Environmental Protection, Safety, and Health Protection Standards
	Order 5480.9,	Construction Safety and Health Program
	Order 5480.10,	Contract Industrial Hygiene Program
	Order 5480.11,	Radiation Protection for Occupational Workers
	Order 5481.B,	Safety Analysis and Review System
	Order 5482.1B,	Environmental, Safety and Health Appraisal Program
	Order 5483.1A,	Occupational Safety and Health Program for DOE Contractor Employees at government-Owned Contractor-Operated Facilities
	Order 5484.1,	Environmental Protection, Safety, and Health Protection Information Reporting Requirements
	Order 5500.3A,	Planning, and Preparedness for Operational Emergencies
	Order 5700.6C,	Quality Assurance
	Order 5820.2A,	Radioactive Waste Management
	Order 6430.1A,	General Design Criteria

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Impact of phasing out federal coal and oil leases on CO_2 emissions and 2°C goals

Avoiding dangerous climate change will require a rapid transition away from fossil fuels, with some scenarios envisioning a complete phase-out within 50 years. Many countries have taken measures to reduce fossil fuel demand – from pricing carbon to promoting low-carbon energy sources – but progress has not been fast enough, and investment in fossil fuel production has continued to grow.

There is thus a growing interest in policies that directly address fossil fuel supply. In the U.S., one option on the table is to reduce or end the issuance and renewals of U.S. government leases for fossil fuel exploration and extraction on federal lands and offshore waters. Indeed, the Obama administration is reviewing federal leasing practices and considering (at least for coal) whether the future fossil fuel production they would enable is consistent with U.S. emission reduction goals.

This policy brief, based on an SEI working paper, examines how ceasing further leases would affect coal, oil and gas production; consumption, and resulting global carbon dioxide (CO_2) emissions. It also explores how such decisions might affect progress towards the Paris Agreement's goal of keeping warming "well below" 2°C above pre-industrial levels and pursuing efforts to limit the increase to 1.5°C.

Key findings

- Since 2010, U.S. fossil fuel production has grown by 20% in energy terms,[1] to record levels. About a quarter of the fuels being extracted, including two-fifths of all coal, come from federal lands and waters leased to producers by the U.S. Department of Interior (DOI).
- To be consistent with the goal of keeping global warming below 2°C, the U.S. would need to cut aggregate fossil fuel production by 40–60% from current levels by 2040. Under current policies, however (including the Clean Power Plan), production is expected to rise by 11%.
- Ceasing to issue new leases for fossil fuel extraction on federal lands and waters, and avoiding renewals of existing leases for resources that are not yet producing, would likely lead to a steady decline in U.S. coal production. Oil and gas extraction would likely drop as well, but more slowly.
- Phasing out federal leases for fossil fuel extraction could reduce global CO_2 emissions by 100 million tonnes[2] per year by 2030, and by greater amounts thereafter – an impact comparable to that of other major climate policies under consideration by the Obama administration.

A bustling industry faces new questions

The U.S. now produces more fossil fuels than ever. It ranks first in the world in oil and gas production, and second in coal production. Since 2010, U.S. fossil fuel production has grown by 20% in energy terms, due in great part to technology advances in extracting oil and gas from tight and offshore resources. Increased production has helped natural gas eclipse coal as the top fuel for U.S. electricity production, slowing growth in CO_2 emissions.

And despite current low oil prices, investment in fossil fuel extraction and trade infrastructure continues. For example, investments in new U.S. oil exploration and production infrastructure in 2015 amounted to $100 billion – down from an all-time high in 2014, but still among record levels, and expected to be surpassed again by 2018. Investments in capital-intensive, high-carbon fuel infrastructure can lock in long-term fuel supplies and tie communities to fossil fuel revenues, making it more difficult and expensive to later shift to a low-carbon pathway.



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A shovel loads coal into a haul truck, while a dragline uncovers a new stretch of coal seam, at the North Antelope Rochelle mine in Wyoming, the largest coal mine in the U.S .

About a quarter of all U.S. fossil fuels extraction (in energy terms), including two-fifths of all coal, occurs on federal lands and waters.[3] Producers obtain leases for these activities from the U.S. Department of Interior (DOI) through bids and auctions, and pay fees, rents and royalties that are shared by the federal government and state and tribal governments.

These leasing systems have been in place for generations and are a significant source of government revenue, including for local communities. Yet in recent years, climate and other concerns have raised new questions about those practices. In his 2016 State of the Union address, President Obama called for a change in how U.S. oil and coal resources are managed, to "better reflect the costs they impose on taxpayers and our planet".

1 For ease of comparison, much of the analysis in this paper presents coal, oil and gas production in energy-equivalent terms, as quadrillion British thermal units (QBtu).

2 We use "tonnes" to distinguish metric tons, the unit here, from short tons, a commonly used U.S. weight measure.

3 Hereafter we refer simply to "federal lands" to encompass both lands and offshore areas that are subject to federal leasing provisions.

Just days later, the DOI announced an environmental review of the federal coal leasing program to, among other goals, consider "adjustments to the scale and pace of leasing", and "whether the leasing and production of large quantities of coal… is consistent the Nation's goals to reduce greenhouse gas emissions". Legislation has also been introduced in Congress to stop all future leasing activity. In addition, royalty regimes are being re-examined, with an eye to eliminating apparent subsidies or possibly applying a carbon charge.

The debate about federal fossil fuel leases is complex, involving not only climate considerations, but also questions about broader environmental protection, government revenue, jobs, and the resilience of regional economies that now depend heavily on fossil fuel production. Our analysis focuses on the climate implications, aiming to fill what we see as a critical knowledge gap.

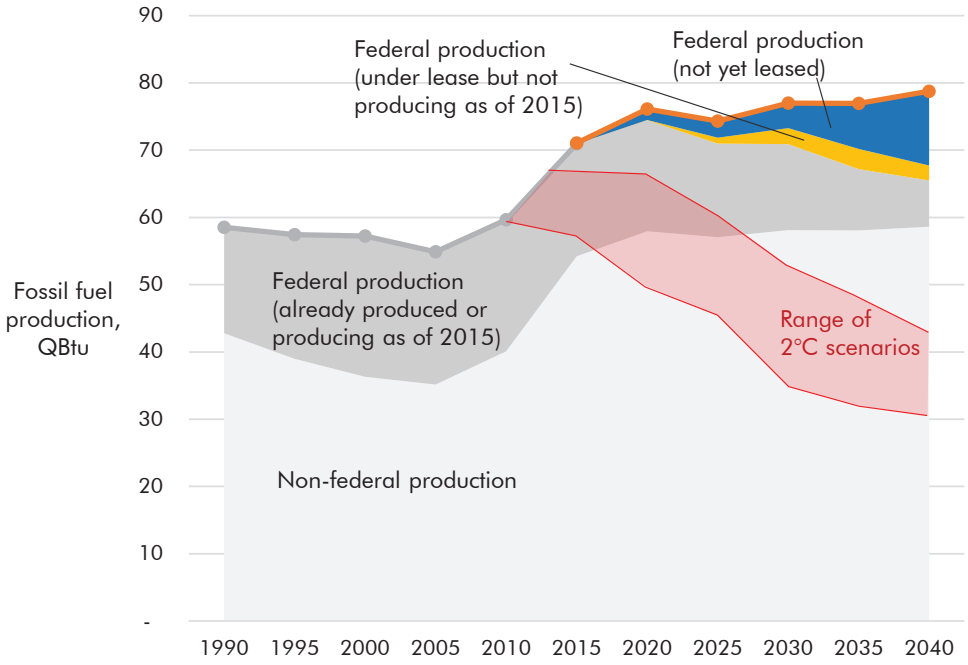


Figure 1: Historical and forecast U.S. fossil fuel production, by status of federal lease, 1990–2040, quadrillion BTU

Source: SEI analysis based on ONRR (2015), U.S. EIA (2015a; 2015b), assuming implementation of the Clean Power Plan; McGlade and Ekins (2015); International Energy Agency (2015).

Specifically, we review recent U.S. fossil fuel production and explore future trends; show how future U.S. fossil fuel extraction might need to decline under a 2°C pathway; analyze how fossil fuel production might be affected if the U.S. government stopped issuing new leases; and estimate the resulting impact on overall energy use, CO_2 emissions and progress towards a 2°C pathway.

Implications of a phase-out of federal leases

Recent U.S. Department of Energy projections show U.S. gas production rising continuously through 2040, oil production peaking within the next 10 years, and coal production dropping as the Clean Power Plan takes effect, then rising slowly again over time. Overall, fossil fuel production would be 11% higher in 2040 than in 2015. We use these projections as our reference case, and contrast it with scenarios from two recent global studies which suggest that under a cost-efficient 2°C pathway, U.S. aggregate fossil fuel production would need to drop by 40–60% from current levels by 2040.

One way to help bring U.S. fossil fuel production more closely in line with a 2°C pathway could be for the DOI to stop issuing new leases for fossil fuel extraction on federal lands and waters, and to end existing leases when they come up for renewal if the resources are not yet producing. As shown in Figure 1, by 2040, about two-thirds (13 quadrillion British thermal units, QBtu) of expected federal fossil fuel production (20 QBtu) will come from lands not yet under lease or under lease but not yet producing. Figure 1 also shows the range of U.S. fossil fuel production under the two 2°C scenarios we considered.

Of the prospective federal fossil fuels from areas not yet leased or producing (orange and dark blue areas in Figure 1), about half is coal, mostly from Wyoming's Powder River Basin. Indeed, by 2030, the majority of federal coal will come from new leases. As shown in Figure 2, total U.S. coal production is expected to drop sharply after 2020, partly as the result of the Clean Power Plan, then rebound gradually (as Clean Power Plan targets have yet to be extended beyond 2030). In a cost-efficient 2°C scenario, however, total U.S. coal production would likely need to keep declining rapidly, by between 60% and 98% from 2015 levels, by 2040.

As shown in Figure 2, of all three fossil fuels, gas has the lowest fraction (less than one-fifth) produced from federal lands and waters. About half of this gas is from land in Rocky Mountain states, especially Wyoming and Colorado. About a third is from offshore deposits, almost all in the Gulf of Mexico.

Gas (and oil) projects tend to have longer lead times than coal, as gas companies must first conduct exploratory drilling and put wells or offshore platforms in place. (By contrast, new federal coal leases are often next to existing mines and can be accessed readily with existing equipment.) New leases would produce only a negligible amount of gas before 2030, so a change in leasing practices for gas might take many years to affect production.

Slightly more than one-fifth of current and expected U.S. oil extraction is from federal lands and waters, and most of that (about 70%) is offshore. And as with gas, oil projects have long lead times – especially offshore oil. Thus, a change in leasing practices would not have much impact on oil production until after 2030. However, as production from existing fields declines more rapidly in later years, the importance of new leases grows.

Implications for energy use and global CO_2 emissions

Some argue that reducing production in one location would simply lead to corresponding increases elsewhere – a "whack-a-mole" phenomenon. However, our analysis indicates that increases in other fuels make up only part of the avoided pro-

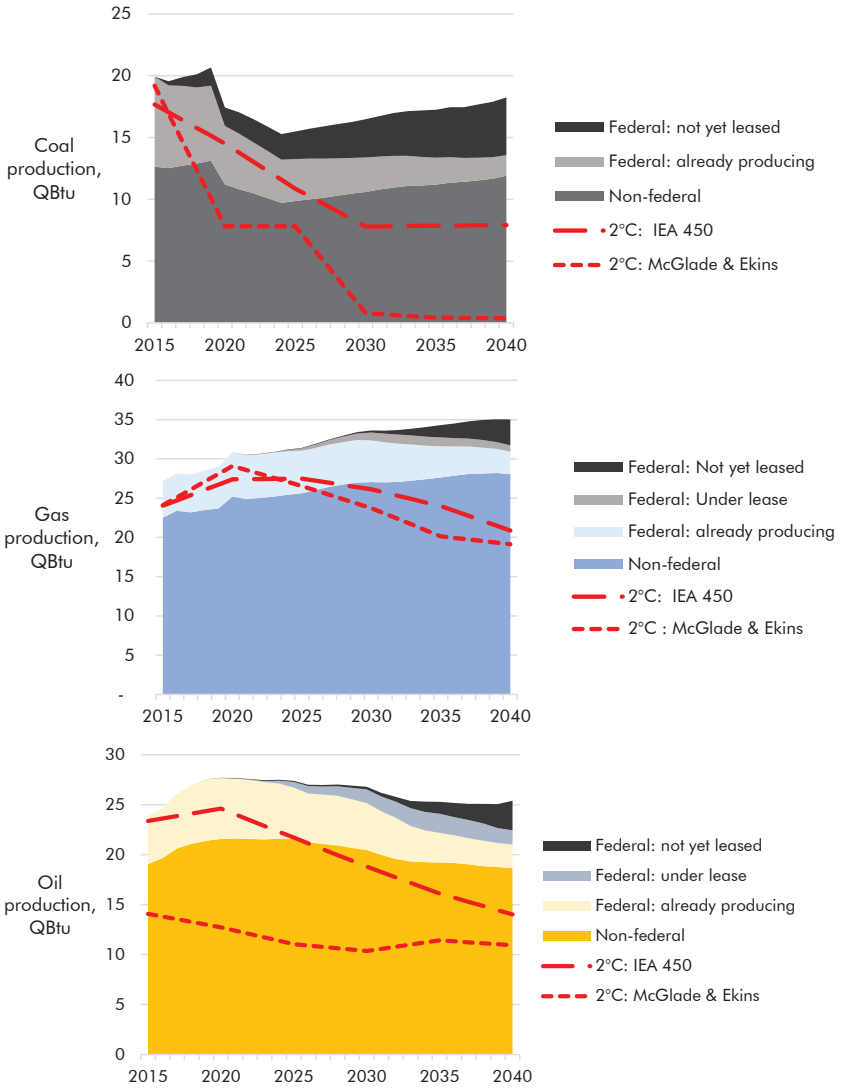


Figure 2: Future U.S. fossil fuel production in reference case (by status of federal lease) and under 2°C scenario, 1990-2040

duction, so a lease restriction policy would likely lead to net CO_2 emission reductions.

To analyze the net CO_2 emissions effects, we use economic analysis tools to consider the effect of reduced production from federal lands on energy prices, and in turn the effect of price increases on energy consumption and the use of substitute resources. This enables us to estimate impacts on overall fuel use and global CO_2 emissions. For example, for a given amount of coal not extracted from federal lands, we estimate how much other (non-federal) coal production would increase, how much natural gas and lower-carbon resources might substitute in power markets, and how much overall energy use might decline.

We focus our analysis on coal and oil, as federal leasing of these resources is likely to have the greatest impact on global CO_2 emissions. The net effect of natural gas supply on CO_2 (or total greenhouse gas) emissions is more uncertain, especially through 2040. We focus on emissions in 2030, as this is a common reference year for future climate action and commitments under the Paris Agreement.

After accounting for substitution effects, we find that restricting new coal leases would reduce CO_2 emissions from coal in 2030 by about 107 million tonnes (Mt), and increase emissions from gas by about 36 Mt, resulting in a net reduction of 71 Mt CO_2. We estimate that restricting oil leases would reduce CO_2 emissions from oil consumption in 2030 by 54 Mt CO_2 and lead to an increase in CO_2 emissions from other fuels of 23 Mt CO_2, for a net emissions benefit of 31 Mt CO_2. Figure 3 shows each component of our analysis for coal markets.

Overall, annual global CO_2 emissions could drop by about 100 Mt per year by 2030 if the DOI ceased issuance of new and renewed leases for fossil fuel extraction from federal lands and waters. Annual emission reductions could well increase over time, as federal fossil fuel production becomes even more dependent after 2030 on yet-to-be issued leases. Furthermore, over time, consumers are likely to be more responsive to increased fossil fuel prices.

For comparison, recently proposed federal standards for light- and medium-/heavy-duty vehicles are expected to yield 200 Mt and 70 Mt in CO_2 savings, respectively, in 2030. The emission reductions expected from the regulation of oil and gas industry (sector-wide) emissions, or from methane restrictions on oil and gas operations on federal land, are far lower (13 Mt CO_2 and 5 Mt CO_2 respectively). Only the Clean Power Plan would yield substantially greater emission benefits than a change in leasing policy, 610 Mt CO_2. In other words, ceasing to issue and renew federal fossil fuel leases could make an important contribution to U.S. climate efforts.

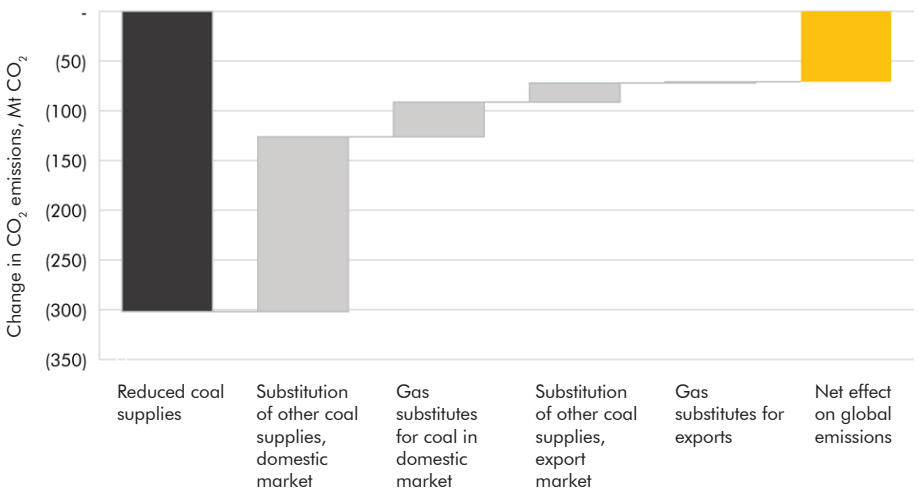


Figure 3: Impacts of decreased coal production on coal and gas markets (assuming Clean Power Plan goes forward) in 2030, in million tonnes CO_2

Policy implications

Federal leasing practices could play an important role in U.S. efforts to achieve its climate protection goals. Should federal leasing continue unabated, the U.S. could be producing 11% more fossil fuel energy by 2040 than it does today – a quarter of it on federal lands. Achieving a cost-effective 2°C pathway, however, would require total U.S. fossil fuel energy production to decline by 40–60% from current levels by 2040.

Ceasing all new federal leases and non-producing lease renewals for fossil fuel production on federal lands and waters would:

- **Send national coal production on a steadily declining pathway**, potentially to levels nearly consistent with a 2°C pathway for U.S. coal extraction.
- **Take longer to play out for oil and gas extraction**, as many oil and gas projects, especially offshore, have substantially longer lead times from lease approval to full production. In that context, most (86%) of the emission reductions from restricted leasing of oil in our analysis in 2030 come from the DOI not issuing offshore oil leases, and most of those are from not renewing existing leases. The impact of ceasing new leases then takes over by 2040.
- **Yield an overall reduction in CO_2 emissions in 2030 of 100 Mt CO_2** (relative to reference case levels), on par with flagship policies of President Obama's Climate Action Plan. Roughly 70 Mt CO_2 of the impact would be from reduced coal use (especially due to cuts in Powder River Basin coal, which is strongly federal), and about 30 Mt CO_2 from reduced oil use (especially due to cuts in offshore oil). These impacts could increase over time, as new, not-yet-issued federal leases comprise an even greater share of national fuel production after 2030.

Alternate scenarios

Several uncertainties underlie our analysis – most prominently, whether the Clean Power Plan will survive legal challenges. We find that, if the Clean Power Plan were not implemented, a phase-out of federal fossil fuel leases would reduce emissions by 270 Mt CO_2 in 2030. This amounts to nearly half the CO_2 savings expected from the Clean Power Plan that year.

Our findings are also sensitive to the response of producers and consumers to changes in energy prices due to reductions in fossil fuel supply. For example, should coal producers respond by more rapidly drawing down their reserves, the impact in 2030 could be smaller, but grow in later years. Conversely, if cessation of federal leasing led to further tightening of finance for the coal industry, then coal production could decline even more rapidly.

The relative ambition of other climate policies also matters. In a world with ever-more fossil fuels available (at low costs) and fewer low-carbon technologies, a change in federal leasing could be mostly offset by other sources of fossil fuels, for a net impact of as little as 4 Mt CO_2 in 2030. By contrast, in a world with shrinking fossil fuel supplies and greater availability of low-cost renewables, the impact of federal leasing policy could be as great as 210 Mt CO_2 in 2030.

In this context, we note that 30% of the estimated emissions reductions in 2030 from a change in leasing policy would occur outside the U.S. That fraction of the reductions would not be reflected in the U.S. national greenhouse gas inventory, which only includes emissions on U.S. territory, but it would help advance global climate goals. It could also send a strong signal to other countries, encouraging them to take similar steps. And it could put U.S. fossil fuel production on a path more consistent with the Paris Agreement's long-term goal to achieve net zero greenhouse gas emissions from human activities in the second half of the century.

This policy brief is based on SEI Working Paper 2016-02, *How would phasing out U.S. federal leases for fossil fuel extraction affect CO_2 emissions and 2°C goals?* by Peter Erickson and Michael Lazarus, available at: https://www.sei-international.org/publications?pid=2937.

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NATURE CLIMATE CHANGE | **ARTICLE**

Limiting global warming to 2 °C is unlikely to save most coral reefs

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Abstract

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Mass coral bleaching events have become a widespread phenomenon causing serious concerns with regard to the survival of corals. Triggered by high ocean temperatures, bleaching events are projected to increase in frequency and intensity. Here, we provide a comprehensive global study of coral bleaching in terms of global mean temperature change, based on an extended set of emissions scenarios and models. We show that preserving >10% of coral reefs worldwide would require limiting warming to below 1.5 °C (atmosphere–ocean general circulation models (AOGCMs) range: 1.3–1.8 °C) relative to pre-industrial levels. Even under optimistic assumptions regarding corals' thermal adaptation, one-third (9–60%, 68% uncertainty range) of the world's coral reefs are projected to be subject to long-term degradation under the most optimistic new IPCC emissions scenario, RCP3-PD. Under RCP4.5 this fraction increases to two-thirds (30–88%, 68% uncertainty range). Possible effects of ocean acidification reducing thermal tolerance are assessed within a sensitivity experiment.

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Coral reef ecosystems provide habitat for over a million species and are important for the socio-economic well-being of approximately 500 million people[1]. At present, reef-building corals persist only within relatively narrow environmental conditions associated with shallow, sunlit and alkaline waters of tropical coastal areas. The carbonate reef structures that result from their calcium carbonate skeletons commonly build up in regions where temperatures exceed 18 °C in winter and aragonite saturation states are greater than 3.3 Ω_{ara} (ref. 2), although high calcification rates are also found in individual locations with aragonite saturation levels of only about 2.85. However, these values belong to the lowest values observed within coral reef ecosystems[3]. Local stressors such as overfishing, pollution, disease and declining coastal water quality are thought to be a major driver of the decrease in living coral cover on reefs over the past several decades[4].

Coral reefs are sensitive to elevated sea temperatures[5], resulting in coral bleaching, which involves the breakdown of the symbiosis between corals and the dinoflagellate symbionts residing in coral tissue. Mass coral bleaching and mortality events have been observed worldwide since the early 1980s and have affected reefs at regional scales (see, for example, ref. 6). For example, during 1997 and 1998, mass coral bleaching events affected coral reefs in almost every part of the world and caused mortality of approximately 16% of reef-building corals[1]. Although corals can re-establish themselves after mass bleaching events, in some cases it takes one to two decades for the ecosystem to return to the pre-bleaching state[7]. An increase in the frequency and severity of mass coral bleaching could overwhelm the ability of coral reefs to recover between events. If this happens, coral reef ecosystems would shift towards systems that are dominated by other organisms such as cyanobacteria and algae.

A common method for predicting mass coral bleaching and mortality is the accumulation of thermal stress, in the form of degree heating weeks (DHW), computed from *in situ* or

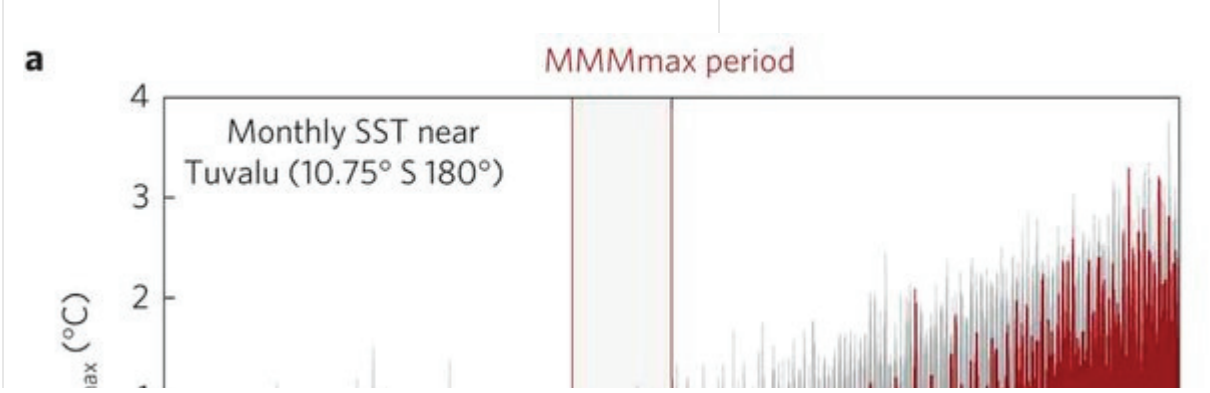
satellite-derived sea surface temperature (SST) data[8, 9]. Future projections of coral bleaching using the output of AOGCMs have been made using a similar degree heating months (DHM) metric, which is better suited to the monthly data provided by AOGCMs. The DHM value is the accumulated SSTs above the mean of maximal monthly temperatures (MMM_{max}) from a climatological base period[10]. A DHM total of 1 °C×month was used as the best indicator for the lower bleaching threshold (DHW>4 °C×week) whereas a DHM value >2 °C×month was associated with an upper, or severe, bleaching threshold (DHW>8 °C×week; ref. 11).

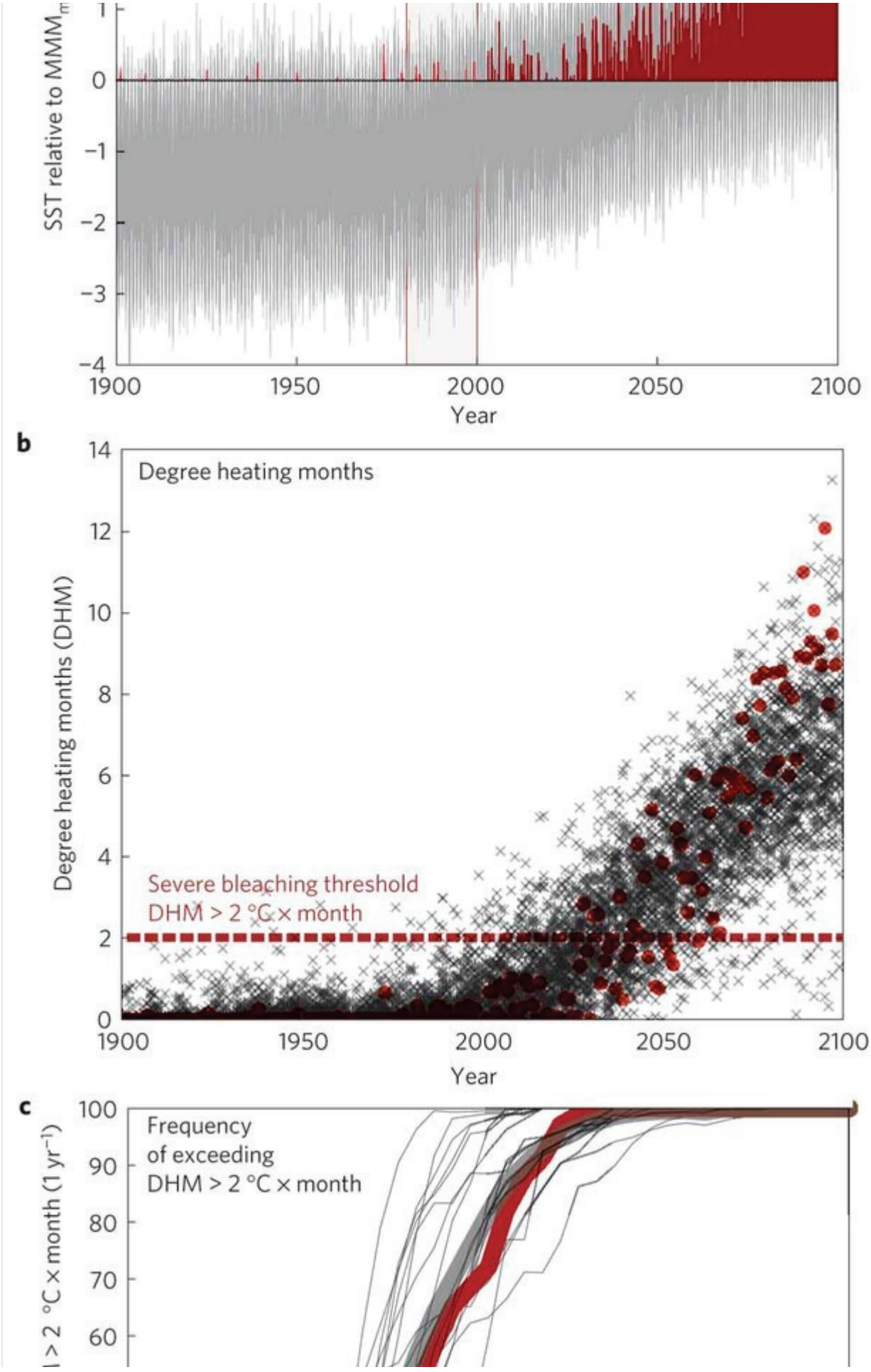
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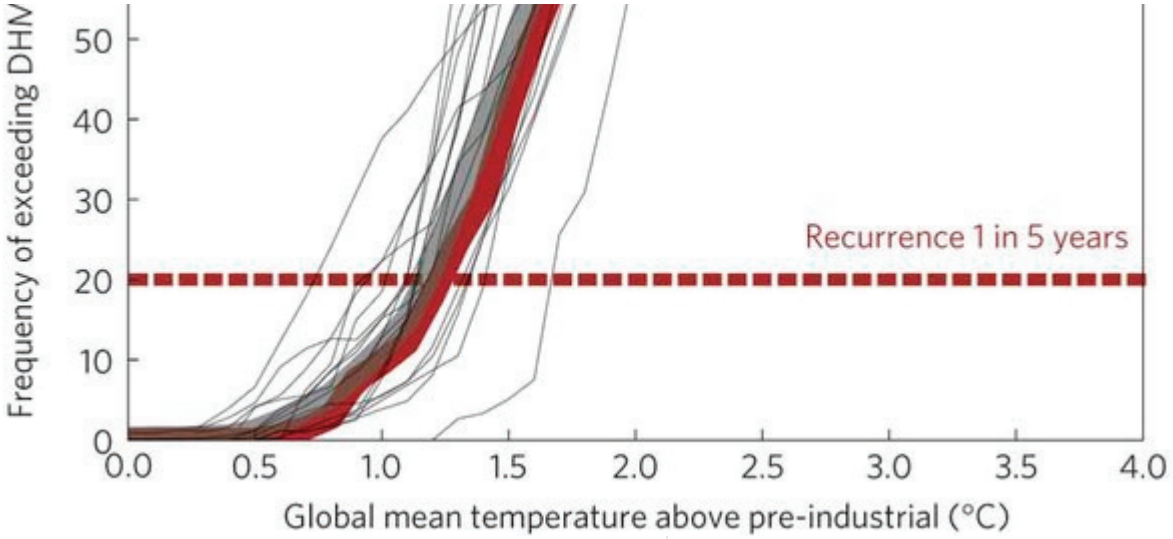
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We provide a comprehensive global analysis of bleaching under different levels of global warming using the DHM method (Fig. 1). This analysis provides three key advances on previous work. First, we take advantage of the close relationship, quasi-independent of the future scenario, between mean regional and global warming levels computed by AOGCMs (ref. 12) to calculate the fraction of coral reef cells at risk of high thermal stress in terms of the global mean surface air temperature change, rather than the time period in a particular emissions scenario. This allows us to derive an essentially scenario-independent description of coral reef response to different levels of global warming. So far, bleaching indicators at different levels of global warming were also considered in ref. 13 for the Caribbean region and two individual AOGCMs.

Figure 1: Heat stress projections at the example location of Tuvalu (10.75° S, 180°).




SST relative to MMM$_m$
1
0
−1
−2
−3
−4
1900
1950
2000
2050
2100
Year
b
Degree heating months
Degree heating months (DHM)
14
12
10
8
6
4
2
0
Severe bleaching threshold
DHM > 2 °C × month
1900
1950
2000
2050
2100
Year
c
Frequency
of exceeding
DHM > 2 °C × month
> 2 °C × month (1 yr^{-1})
100
90
80
70
60



Data from the mpi_echam5 model are shown in red whereas other AOGCM data are plotted in grey. **a**, Downscaled monthly SSTs of 19 AOGCMs (grey lines) anormalized relative to their maximum monthly mean (here, MMM_{max}) level over the 1980–1999 period, shown for scenario SRES A1B. **b**, Derived degree heating months for the same location. **c**, The recurrence frequency of exceeding DHM≥2 °C×months in Tuvalu relative to the global mean temperature levels. Diagnostics for 19 individually analysed AOGCMs and the ex-post AOGCM average (thick grey line) are shown; the dashed red line corresponds to recurrence 1 in 5 years.

Second, we employ more than 32,000 model years derived from seven scenarios (twentieth century, three Special Report on Emissions Scenarios (SRES), the commitment scenario (COMMIT) and two idealized CO_2-only scenarios) and up to five ensemble members per scenario by 19 AOGCMs that provided output to the comprehensive multi-model CMIP3 (Coupled Model Intercomparison Project phase 3) archive (see Supplementary Section S1) to capture the uncertainty in projected regional SST. This allows for a more robust representation of uncertainty than any previous study. A regional study[14] also followed a multi-model approach but does not provide the linkage to global mean temperature changes.

Third, we employ time-variable thermal bleaching thresholds to illustrate the effect of thermal adaptation and provide exploration of the possible effect of ocean acidification on thermal sensitivity. In our thermal adaptation setting the threshold for severe bleaching events is assumed to increase linearly from 2 °C×month to DHM levels of 6 °C×months or

more in 2100. This is considered to be a theoretical and ambitious level of adaptation given the long generation times of reef-building corals and the consequently slow rate at which evolutionary adaptation occurs. This level of thermal stress has also been extremely rare over the past several decades; it exceeds the maximum reached during the 2005 Caribbean bleaching event[15] and has probably only been reached in the Central Equatorial Pacific during warm El Niño/Southern Oscillation events. Thermal adaptation may in particular include a shift to symbiont species with a higher thermal tolerance, although evidence of this particular adaptation strategy is slim at best[2]. On the community level, repeated thermal stress may shift the community towards more thermally tolerant coral species. Such a shift to more thermally tolerant coral species might be considered as a kind of reef degradation. However, there is also evidence of intra-specific variation in thermal resistance[16, 17, 18]. Given recent debate about the issue of adaptation (for example, refs. 19, 20, 21, 22), we explore a range of possible futures from one with no thermal adaptation over the next century to those that include a highly optimistic level of thermal adaptation. In addition to this specific assumption about adaptation, we also estimate bleaching frequencies for a whole range of different DHM thresholds to estimate the increase of the bleaching threshold necessary to protect a certain fraction of reef cells.

We also conduct a sensitivity analysis assuming that, in combination with the projected warming, ocean acidification may accelerate the degradation of coral reefs during the twenty-first century. Both experimental[23, 24, 25] and field observations [26, 27, 28] indicate that some but not all corals respond to ocean acidification and reduced aragonite saturation through reduced calcification rates. Once the average tropical (30° S–30 °N) aragonite concentration decreases below the saturation level (Ω_{ara}<1), exposed coral skeletons start to dissolve in sea water. Although corals might be able to sustain positive calcification rates through active elevation of carbonate ion concentration within an extracellular calcifying compartment, they are still expected to be subject to severe degradation independent of temperature[29]. Therefore, in our sensitivity experiment we assume that the present temperature-driven degradation of coral reefs will gradually turn into an acidification-driven degradation.

Consideration of thermal stress in combination with other changes such as ocean acidification is important if we are to

gain a full understanding of how future ocean conditions will affect coral reef ecosystems and indeed other ecosystems. The potential effect of thermal adaptation on projected bleaching frequencies has been included in other analyses[10, 14]. In contrast, the potentially opposite effect of ocean acidification on increasing bleaching thresholds has not been considered so far in future projections.

We test different ways in which this possible transition may happen. As the means of the transition is not yet clear we make different assumptions. First we assume that the bleaching threshold linearly decreases from 2 °C×months to 0 °C×months when reaching undersaturation. This approach is based on ref. 30, in which it was proposed that CO_2 may act to create a greater sensitivity of corals to thermal stress. A similar effect was also shown for water pollution[31]. In addition, we consider transitions of the bleaching threshold from 2 °C× to 0 °C×months at other levels of aragonite saturation including a stepwise decrease as a transition not mediated by increasing temperature sensitivities, a delayed decrease starting at lower levels of tropical mean aragonite saturation, and steeper declines because at some point above $\Omega_{ara} = 1$, coral reef structures will probably not be able to counterbalance biological and physical erosion, which is necessary for the maintenance of the all-important carbonate structures of coral reefs[27].

The results of these additional experiments are reported in Supplementary Section S4. They show that delayed onsets of the considered effect of acidification (or possibly other agents reducing thermal sensitivity of corals) may not appear in the results because of the high number of reef cells that are already projected to be at risk of long-term degradation assuming present bleaching thresholds of 2 °C×months.

It is important to note that the estimation of long-term degradation uniformly starts on the present bleaching threshold of 2 °C×months independent of spatial variations of the aragonite saturation. Changes in bleaching thresholds are expressed in terms of the tropical average (30 °S–30 °N) aragonite saturation, thus implicitly assuming that corals are adapted to spatial deviations from this average.

Reef recovery from mass coral bleaching and mortality events varies widely but is usually very limited within the first five years[7, 32]. Therefore, we assume that $0.2\,yr^{-1}$ is the maximum tolerable frequency[10] of recurrent severe thermal stress events (which is otherwise considered to be highly

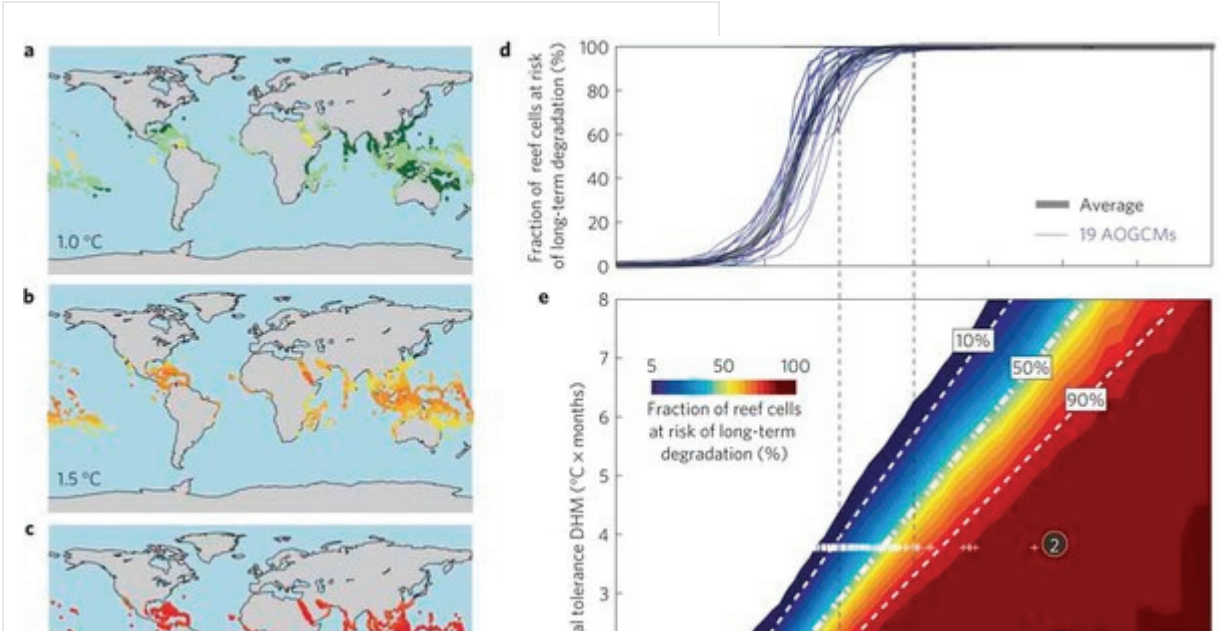
conservative in light of the fact that most recovery takes 10–30 years[7]). If the frequency surpasses 0.2 yr^{-1}, lasting damage are assumed to occur, henceforth referred to as long-term degradation. We calculate AOGCM-specific fractions of years with DHM values >2 °C×months within different global mean temperature bins over all available scenario runs and for each individual coral reef grid cell (see Fig. 1 and Supplementary Section S2). Alternatively, long-term degradation might be assumed as soon as the temporal distance between two DHM>2 °C×months events for a single reef cell is less than 5 years. Both approaches provide similar results, as shown in Supplementary Fig. S3.

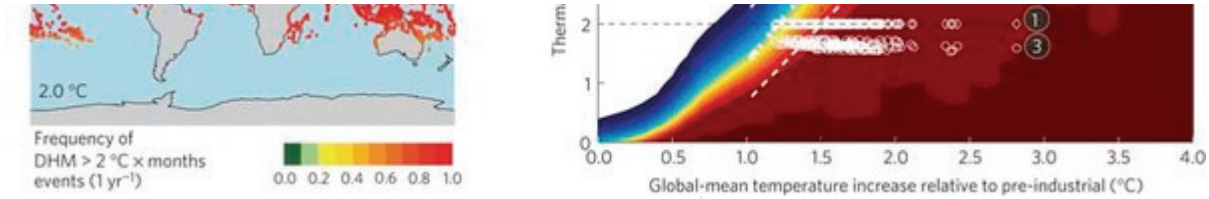
Frequency of bleaching at different global warming levels

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The left panels of Fig. 2 show the frequency of exceeding DHM = 2 °C×month for individual grid cells and in three different global mean temperature bins averaged over all AOGCMs. The frequency of exceeding the bleaching threshold tends to be higher at lower latitudes. This might explain some of the heterogeneity of coral losses found previously[20]. At 1.5 °C global warming, the average projected bleaching frequency is higher than 0.2 yr^{-1} at all reef cells.

Figure 2: Thermal stress at different levels of global warming.





a–**c**, Frequency of DHM>2°C×month events with 1.0 °C (**a**), 1.5 °C (**b**) and 2.0 °C (**c**) of global mean warming. Colour scale indicates the average of the 19 AOGCM-specific frequencies calculated at each coral reef grid point. Green points represent frequencies below 0.2 yr^{-1} and yellow to red points represent frequencies above that critical limit for long-term degradation. **d**, Corals at risk of long-term degradation for constant thermal threshold DHM = 2 °C×month and individual AOGCMs. The average across 19 AOGCMs (thin blue lines) is shown as a thick grey line. **e**, Fraction of the world's coral reef cells (coloured areas) at risk of long-term damage due to frequent (>1 in 5 years) coral bleaching events, depending on global mean temperature (*x*axis) and assumed thermal threshold (*y* axis). A constant DHM = 2 °C×month thermal threshold is indicated by the horizontal dashed line. Two hundred random ensemble members for the 2050 climate state conditions under RCP3-PD with constant thermal threshold (white diamonds, black circled 1), thermal adaptation (white plus symbols, black circled 2), and aragonite-dependent thresholds (white circles, black circled 3) are shown.

The fraction of reef cells, separated by AOGCM, that experience thermal stress at a frequency that might lead to long-term degradation shows an almost stepwise behaviour with increasing global mean temperatures (see Fig. 2d). The thick grey line represents the AOGCM average over the individual fractions. This ex-post average can be opposed to an ex-ante average where all AOGCM simulations are treated as if they were ensemble members of a single AOGCM and the fraction of affected reef cells was based on that ensemble. Arguments for the ex-post averaging are given in Supplementary Section S5.

The results indicate that there would be long-term degradation of coral reef ecosystems in all present coral reef cells without a change in thermal tolerance (DHM>2 °C×months) at 2 °C global mean temperature rise, an upper limit agreed to in international climate policy negotiations[33] (Fig. 2d). This result is robust across different AOGCMs, with the lowest value being that 98% of coral reefs are subject to long-term degradation (Table 1). Even at 1.5 °C global mean warming, an alternative international

temperature goal to be reviewed for international policy 2015 (ref. 33), our results suggest that around 89% (63–100%) of coral reef ecosystems would face long-term degradation assuming no change in thermal tolerance (Fig. 2d). At the present rate of warming (~0.2 °C/decade), a 1 °C warming above pre-industrial levels is going to be surpassed in the coming one or two decades, which might already put 16% (3–29%) of reef locations at risk.

Table 1: The fraction of reef cells at risk of long-term degradation for global mean warming relative to pre-industrial levels (top rows).

We find a quasilinear relationship between the required thermal tolerance (DHM) and global mean temperature change (ΔT) for any given fraction of reef cells (x) at risk of degradation (see Fig. 2e). Thus, the required bleaching threshold is given by $\mathrm{DHM}(\Delta T,x) = y_{0,x} + m_x \Delta T$ with the coefficients $y_{0,x}$ and m_x provided in Table 2. These coefficients were derived for our ex-post average results across 19 AOGCMs for global warming levels in excess of 1 °C relative to pre-industrial levels. Above 1 °C of global warming, a thermal adaptation of 3.5, 3.1 and 2.6 DHM per degree of global warming would be necessary to offset the increased thermal stress such that no more than 10%, 50% or 90% of coral reef locations face the risk of long-term degradation, respectively.

Table 2: Regression results for the necessary thermal tolerance of corals (DHM) depending on the global mean warming (ΔT) relative to pre-industrial levels and the fraction of reef cells that will be at risk of long-term degradation (x).

The results broadly agree with those of a previous study[10] on the basis of a comparison of projections for single SRES scenarios (Supplementary Fig. S6) and ref. 34. We specifically test whether the inclusion of spatially coarser AOGCMs (coarser than 1.5° longitudinal ocean resolution) might have biased the results of this study (Supplementary Table S1). The global mean temperature that corresponds to 50% of coral reefs being at risk of disappearance given a DHM>2 °C×months thermal tolerance is 1.23 °C relative to pre-industrial levels on average across all 19 diagnosed AOGCMs. For the 9 lower- or 10 higher-resolution models, this average does not change noticeably, that is, 1.22 °C and 1.24 °C, respectively, indicating no evidence for such a bias.

Frequency of bleaching under different RCP scenarios

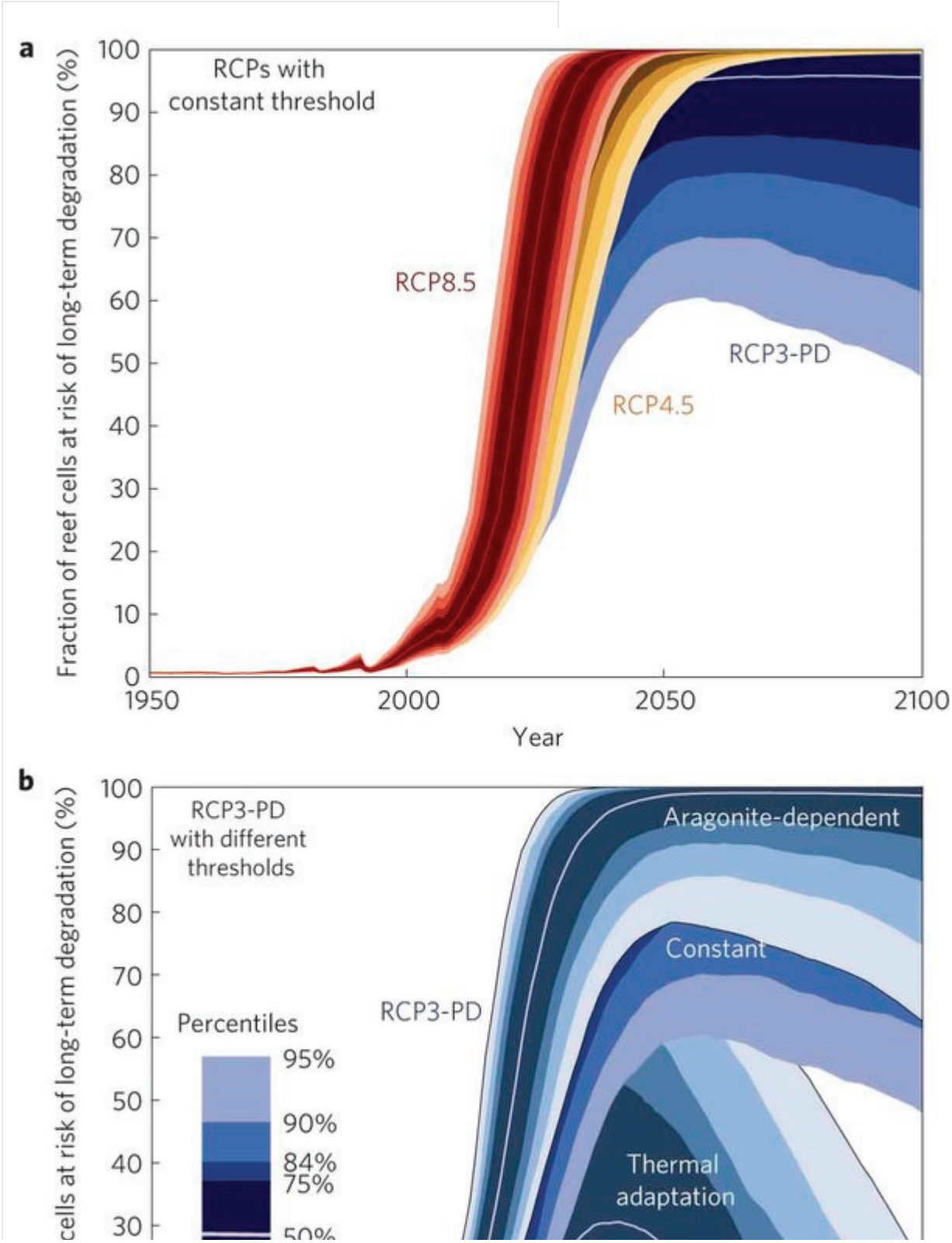
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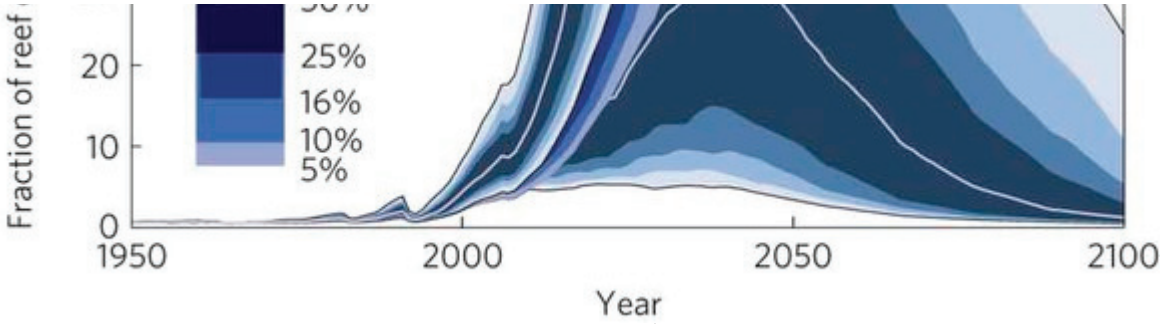
To put the different levels of global warming into perspective and to explore possible effects of thermal adaptation and ocean acidification on bleaching thresholds, we project global mean warming levels and CO_2 concentrations probabilistically for the harmonized emissions of the Representative Concentration Pathways (RCPs) developed for the Fifth Assessment of the Intergovernmental Panel on Climate Change (IPCC; see Supplementary Section S8). A Markov chain Monte Carlo method was used to constrain parameters of our reduced complexity climate model with historical observations, and we emulated nine carbon cycle models that were part of the C^4MIP intercomparison to capture uncertainties related to the carbon cycle[35].

Figure 2e shows samples of the 2050 projections for the strong mitigation RCP-3PD scenario in the global mean temperature–bleaching threshold plane. In our standard case (white diamonds), we assume that the thermal tolerance of corals will not change over the coming decades to any real extent. For the lowest emission scenario, RCP3-PD, the projected global mean temperature increase by 2050 ranges from 1.0 to 1.5 °C relative to the 1980–1999 period, or 1.5–2.0 °C relative to the pre-industrial period. Half of the individual realizations of our historically constrained global mean temperature projections for RCP3-PD for the year 2050 find long-term damage to >95% of coral reefs, assuming no change in thermal tolerance (Supplementary Section S7). The projected degradation is widespread despite the fact that RCP3-PD presents the strongest mitigation scenario investigated at present for the IPCC AR5. For higher RCP scenarios, without a change in thermal tolerance, it is only a question of the time before most of the world's coral reefs face long-term degradation: by the end of this century, 100% of reef cells experience thermal stress (DHM>2 °C×months) at sufficiently high frequency (>0.2 yr^{-1})—even under the lowest projected temperature increase (Supplementary Fig. S4 and Table S2)—to suggest long-term degradation from frequent coral bleaching events. In the thermal adaptation case, the bleaching threshold reaches 4

°C×months by 2050 (white crosses). The fraction of coral reef cells that might be subject to long-term degradation can also be projected for other years and RCP scenarios (see Fig. 3).

Figure 3: Projected probabilistic fraction of the world's coral reefs subject to long-term degradation under the RCPs.





a, Default projection, assuming a constant thermal threshold DHM = 2 °C×months and a five-year return period as leading to the demise of coral reefs. The colour steps mark the percentiles that are indicated at the colour bar in **b**. **b**, Under the scenario RCP3-PD, thermal adaptation (lower grey shaded areas), and aragonite-dependency (upper saturated blue shaded areas), decreases and increases the projected fraction of coral reef subject to long-term damage when compared with the default constant thermal threshold, respectively (see Table 1). See expanded Supplementary Fig. S5.

The thermal adaptation scenario results reveal that two-thirds of the world's coral reefs would avoid long-term degradation under RCP3-PD (Fig. 3b and Supplementary Table S2). Declining temperatures would make 99% (95% to 99%, 68% uncertainty range) of the coral reef cells suitable for the survival of corals again by the end of the twenty-first century. The thermal adaptation scenario is likely to be optimistic given the combination of other stressors on coral reefs and the present downward trajectory of coral cover (for example, ref. 4). There is little experimental or observational evidence for the rapid evolution of thermal tolerance in reef-building corals, which tend to have long generation times (5–100 years) although corals might profit from generation times of the symbionts that are orders of magnitude shorter. The last mechanism is problematic, however, as the thermal tolerance of reef-building corals is not solely determined by the symbiont and requires host evolution as well. Previous palaeontological studies highlighting the resilience of corals even under high CO_2 concentrations and warming tend to explore conditions at long-term equilibrium, over timescales of thousands of years, not decadal or centennial timescales[19, 20], with more pronounced ocean acidification in the latter owing to the lag time in geological processes such as weathering. In addition, thermal adaptation capacities are likely to differ strongly between coral species, coral growth forms and habitats. The aggregate thermal tolerance for coral communities may increase as total coral cover and

diversity declines, because selective coral mortality during bleaching events may lead to survival of only bleaching-resistant or resilient growth forms and species, or of corals in specific thermal refuges. The narrowing of coral gene pools as a result of these processes is likely to decrease the resilience of corals to other impacts such as disease and competition from other benthic species.

In cases of both constant or aragonite-dependent thermal thresholds, the period that corals would have to bridge in unfavourable environments will be on the timescale of centuries, certainly beyond 2100 (see Fig. 3). New stable ecosystems, dominated by macro-algae or other biota, could further hinder any recovery[36]. We did not investigate the multiple synergistic effects of changing environmental conditions on coral reef systems, such as pollution, fishing pressure or other climate-related variables such as cloudiness and coastal runoff.

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Despite the inclusion of optimistic scenarios concerning rates of evolutionary adaptation, our results confirm that coral reef ecosystems face considerable challenges under even an ambitious mitigation scenario that constrains global warming to 1.5 °C above pre-industrial temperatures. Our projections suggest that most coral reefs will experience extensive degradation over the next few decades given the present behaviour of corals to thermal stress[10, 37]. To protect at least 50% of the coral reef cells, global mean temperature change would have to be limited to 1.2 °C (1.1–1.4 °C), especially given the lack of evidence that corals can evolve significantly on decadal timescales and under continually escalating thermal stress. There is little doubt from our analysis that coral reefs will no longer be prominent within coastal ecosystems if global average temperatures exceed 2 °C above the pre-industrial period. Effective conservation of coral reefs in the face of changing climate and ocean chemistry is likely to depend on our understanding how these other variables affect coral reef resilience. There is little precedent for the rate and magnitude of warming in the recent geological history of corals, including the transition into

the warm Eemian period[38]. Further *in situ* observations and laboratory studies will help refine our understanding about the aggregated likely effects of acidification and warming for individual coral reef ecosystems. Despite these uncertainties, the window of opportunity to save large fractions of coral reefs seems small and rapidly closing.

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Calculation of DHM.

As is the case for the DHW used for real-time prediction of coral bleaching events[8, 9], the DHM sums the excess warming above the MMM_{max} of the climatological 1980–1999 base period in a rolling 4-month window[10] (see Supplementary Section S2). To quantify the global extent of bleaching events we use a 0.5°×0.5° map indicating 2160 geospatial locations of coral reefs worldwide from Reefbase (see www.reefbase.org) as adapted by ref. 10. DHM at each of these grid points were calculated after employing a simple linear downscaling of SST data to obtain temperature projections at the coral reef cells' locations. The downscaling/interpolation is based on the four closest AOGCM grid points to every coral reef cell, taking into account the AOGCM-specific land–sea masks and resolutions (see Supplementary Section S1). The difference from an approach that merges satellite and AOGCM data at individual locations was found to be minor for the SRES scenarios (see Supplementary Fig. S5).

The employed bleaching thresholds of 1 °C×month (mild bleaching event comparable to DHW>4 °C×week) and 2 °C×month (severe bleaching event comparable to DHW>8 °C×week) were derived from observed bleaching events on the community level[11]. They do not distinguish between species that might show distinct thresholds [20].

Calculation of aragonite-dependent thermal thresholds.

This translation of CO_2 concentrations to surface aragonite saturation is enabled by the fact that tropical surface aragonite saturation levels are, on a timescale of years to decades, in equilibrium with atmospheric CO_2 concentrations. Thus, we were able to closely emulate zonal ocean chemistry

simulations[39] using a linear rational function (Supplementary Fig. S1). In our Monte Carlo approach, we draw doublets from the joint distribution of global mean temperature and CO_2 concentrations of our probabilistic RCP projections, translate the CO_2 concentrations to aragonite levels and apply the simplified aragonite-dependent thermal threshold.

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Competing financial interests

The authors declare no competing financial interests.

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EDITORIAL

Climate hotspots: key vulnerable regions, climate change and limits to warming

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Abstract Defining and operationalizing Article 2 of the UNFCCC remains a challenge. The question of what is dangerous climate change is not a purely scientific one, as danger necessarily has a subjective dimension and its definition requires judgment and precaution. The papers in this special issue of Regional Environmental Change attempt to navigate this problem, by offering an overview of the latest scientific findings in the context of risks and uncertainties, and assess some key vulnerabilities that might lead to dangerous climate change. This synthesis provides an overview of the papers in this issue and looks at four areas of possible dangerous climate change—adverse declines in regional food and water security, loss of arctic sea ice with projected extinction of species, large-scale sea-level rise and loss of coral reef systems. These issues affect a number of different regions including Africa, South Asia, and Small Island Developing States. Significant risks to vulnerable regions and systems at warming levels of 1.5–2°C above pre-industrial are identified. The direct effects of CO_2 concentration increases in terms of ocean acidification are identified as relevant to Article 2 because of the risks posed to coral reefs. Ultimate CO_2 stabilization levels that allow for the long-term viability of coral reefs likely are below 350 ppm. The paper concludes by arguing that the emission reduction pledges made by countries under the Copenhagen Accord will not suffice to prevent dangerous climate change.

Keywords Climate change impacts · Warming levels · Dangerous climate change

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Introduction

The papers in this special issue of Regional Environmental Change address the question of what may be dangerous levels of climate change: the papers describe and analyse the vulnerability of human and natural systems in a number of regions around the world. The question of what is dangerous clearly relates to values and judgements about risk, and so is not a purely scientific one according to a widespread view of science. However, it is not a purely normative question either: it requires the ability and willingness to navigate the landscape between the two poles of pure factual description and pure normative evaluation. Scientists are often reluctant to express judgements, but in the papers collected in this special issue, after presenting scientific results, the authors have applied their own criteria and judgements for reaching what they see as reasonable conclusions. In some cases, authors have indicated changes that they consider to be dangerous, in others they have pointed to risks, vulnerabilities and uncertainties, which preclude in their view reaching conclusions at this point. Decisions are often made under uncertainty and based on perception and personal judgements. For this reasons, we

believe that the articles in this special issues provide a necessary overview of what might be considered as dangerous climate change.

Climate change is a global challenge. Scientific evidence has often failed to translate into stringent and effective policies. Investments in clean technologies and in adaptation are considered costs to society and often opposed to the need to safeguard the economy. Short-term criteria are usually applied to measure success in our societies, and we systematically fail to realize that investments in transforming our economies are not costs, but rather, indeed investments in the future.

In this context, it is important to address the questions raised by Article 2 and try to define what dangerous climate change might be. Article 2 calls for a judgement, based on experience, scientific results and, when necessary, the precautionary principle. Scientists, policy makers and society at large need to take decisions and to act to prevent danger from becoming disaster.

In this paper, we review the context of what is dangerous climate change under the terms of the United Nations Framework Convention on Climate Change (UNFCCC), we look at some of the issues involved in deciding what might be dangerous and why one would wish to make such a determination, and then attempt to draw some lessons for future consideration of the question by the scientific and policy community.

Preventing dangerous anthropogenic interference with the climate system

Article 2 of the UNFCCC has a far reaching and broad ultimate goal (for a review of its origins see Oppenheimer and Petsonk 2005). It requires that the Parties to the Convention, essentially the entire world community, work together to *prevent* dangerous interference with the climate system. In full, Article 2 states that:

> "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner." (UNFCCC 1992).

Article 2 has several interrelated elements and which are themselves linked to other parts of the Convention:

- Stabilization of greenhouse gas concentrations in the atmosphere
- Prevent dangerous anthropogenic interference with the climate system
- Within a time frame sufficient to:
  - Allow ecosystems to adapt naturally to climate change,
  - Ensure that food production is not threatened
  - Enable economic development to proceed in a sustainable manner.

Stabilization of greenhouse gas concentrations is specifically linked to levels that would "prevent dangerous interference with the climate system", and these levels are to be achieved "within a time frame" sufficient for criteria (ecosystems, food production and economic development) to be met (Verheyen 2007). There is no specific reference to a particular timeframe by which this stabilization should be achieved, nor its manner, and this is open to be decided based on the criteria in Article 2. It is open, for example as to whether, concentrations would rise above an ultimate stabilization level, before falling back, providing that in the end anthropogenic interference with the climate system is prevented.

Legally, it has been argued that Article 2 represents a prevention duty with consequential legal obligations that limits discretion for interpreting the term "dangerous" and that carries with it an obligation to take specific action to achieve this goal, including negotiating specific commitments to reduce greenhouse gas emissions (Verheyen 2007).

The term "dangerous" is important for the interpretation of Article 2. The ordinary meaning of the word is that if something is able, or likely, to inflict injury or harm, or involves exposure to danger, then it is dangerous. A "dangerous" interference with the climate system then must be something that may cause harm or loss. Article 2 demands a judgment as to whether something is likely to cause harm or loss and how significant this may be. A change in the state of the climate system is not in itself dangerous, but its consequences may be.

What is important in the context of the UNFCCC is that specific groups of countries are recognized as most vulnerable, and legally this implies that any definition of the term 'dangerous interference' needs to be oriented towards these countries and not necessarily towards the most resilient countries and regions (Verheyen 2007). Amongst the regions recognized as the most vulnerable are the small island developing states, least developed countries and mountain regions.

The term "dangerous anthropogenic interference" (DAI) is not limited to short-term risks, but also to levels of climate change that may trigger highly adverse changes to

components of the climate system that could take centuries to millennia to be fully felt. Examples include levels of warming that may not pose immediate threats, but in the future could result in the partial or complete loss of the Greenland and/or West Antarctic ice sheets, or cross other tipping point thresholds (Kriegler et al. 2009; Lenton et al. 2009; Malhi et al. 2009).

Apart from global warming itself, dangerous anthropogenic interference with the climate system[1] could occur as a result of increases in carbon dioxide (CO_2) concentration causing ocean acidification (Orr et al. 2005), with the level of acidification largely independent of climate changes induced by elevated GHG concentrations (Cao et al. 2007; McNeil and Matear 2007). Ocean acidification adversely affects a basic aspect of the climate system and has consequences for ecosystems and human food production dependent upon marine organisms. Of current anthropogenic CO_2 emissions, about 30% is absorbed by the oceans, in response to the higher CO_2 concentration of the atmosphere (Denman et al. 2007). The acidity of the ocean waters rises when additional CO_2 is absorbed. The increase in atmospheric CO_2 concentration from 278 ppm in the pre-industrial period to over 387 ppm in 2009 has led to an increase in the ocean's acidity, estimated at a reduction of 0.1 units of pH since pre-industrial (Meehl et al. 2007).

Increasing ocean acidity poses a threat to many marine species and ecosystems and their productivity (Bates et al. 2009; Comeau et al. 2009; Feely et al. 2009; McClintock et al. 2009; Moy et al. 2009; Crawley et al. 2010; Manzello 2010; Shi et al. 2010), although uncertainties persist (Hendriks et al. 2010). It has become clear in the last few years that the onset of serious consequences of ocean acidification on marine may be contemporaneous with serious warming induced consequences on the same systems and species. Hoegh-Guldberg (2010) points towards serious and contemporaneous pressure on coral reefs from both acidification and warming: others have indicated serious risks for Arctic and Antarctic systems within several decades (McNeil and Matear 2008; Steinacher et al. 2009; McNeil et al. 2010).

The three broad themes highlighted in Article 2—ecosystems, food production, sustainable economic development—provide some guidance as to its interpretation. Greenhouse gas concentrations must be stabilized in such a way and within a timeframe that ecosystems can adapt naturally, food production is not threatened and that economic development is able to proceed in a sustainable manner.

[1] UNFCCC Article 1.1 defines the climate system quite broadly as "the totality of the atmosphere, hydrosphere, biosphere and geosphere and their interactions".

Defining what it means for ecosystems to adapt naturally is quite difficult and may be best approached by examining the effects of climate change on key ecosystem properties, services and values. Substantial loss of, or damage to, properties such as biodiversity including conservation of species, food production and provision of livelihoods, may be relevant measures of ecosystem response to climate change. Large changes in the spatial extent and geographical location of ecosystems could be other measures.

Midgley and Thuiller (2010) provide an example from southern Africa of large-scale projected damages to ecosystem values. With about a 2°C warming they predict for the endemic flora of southern Africa an average reduction by about 40% in habitat-specific species richness. For a higher warming of 3–3.5°C, projections for 5,197 African plant species show that 25–42% could lose all suitable range by 2085. For Australia, Hughes (2010) shows quite high risks for warming in the range of 1.5–2°C for the Australian Alpine region, the Great Barrier Reef, World Heritage rainforests and wetlands. In Europe, Alkemade et al. (2010) show an increasing and substantial risk of extinction with increasing warming, so that by around 3°C warming, 25% of the species are projected to disappear from Mediterranean Europe and Northern European ecosystems are transformed with 35% of species there newly introduced.

Ni (2010) has looked at ecosystem changes in China and shows that large and rapid movements in ecosystems are projected. The loss of grasslands, high elevation meadows and steppe in particular could lead to losses of biological diversity. The Tibetan Plateau is one of the more sensitive regions containing many unique environments that are very sensitive and vulnerable to climate change and human disturbances. Warming of this region will accelerate the loss of permafrost and thereby contribute to the process of desertification (Ni et al. 2000). Meadows on the plateau would be reduced in extent (Zhao et al. 2002). Studies on the effects of warming and grazing on high elevation meadows indicate that these pressures could cause large, rapid declines in plant species diversity (Klein et al. 2004).

The requirement to ensure that food production is not threatened might appear straightforward; however, the question of regional differences is paramount. Global increases in food production could, for example, be accompanied by reductions at regional levels whose consequences for food security would depend upon the regional context and the socio-economic scenarios assumed both globally and regionally. Is a large regional reduction in food security dangerous under the meaning of Article 2, even whilst globally food production may increase? Assume for example that Indian food production is reduced under warming, as suggested by Lal (2010).

Indians might feel that this would be dangerous and an infringement on their right to development. Elsewhere, however, in regions where crop production has, or is projected to increase, there may be feeling that this is in fact an opportunity for greater exports, or at the least food deficits could be dealt via food aid programmes, in other words by compensation rather than by prevention.

Tao et al. (2010) explore risks for food production in China and in overall terms find that there is insufficient work available to define whether the risks could be dangerous for agricultural production in China, with some likelihood of improved conditions. In common with many other studies of this region, this work shows the importance of the strength of the CO_2 fertilization effect, which remains uncertain. Most studies show little adverse effects in China's food production if CO_2 fertilization works as projected, but significant reductions if not (Xiong et al. 2007a, b; Yao et al. 2007; Tao et al. 2009; Tao and Zhang in press).

Unmitigated climate changes is projected to threaten sustainable economic development in a number of regions, causing significant problems in areas as diverse as health, water supply, agriculture, infrastructure damages and financial and other economic services (IPCC 2007). Barnett (2010) in his paper argues that the projected adverse impacts on the economic development of small islands is dangerous. Direct threats to communities in mountain regions were identified by Chevallier et al. (2010) for the Andes and Shrestha and Aryal (2010) for the Himalayas. Both papers provide a striking overview of glacial retreat, causing an enhanced risk of glacial lake outbursts and reducing water security during dry seasons. These changes threaten livelihoods directly through increased natural hazards and indirectly due to negative economic impacts on water security and hydro-energy potential. Effective mitigation of climate change may be a prerequisite for sustainable economic development in many regions whilst delayed mitigation and higher levels of climate change could lead not only to increased costs, but also hamper sustainable development.

Beyond these three criteria, however, Crowley (2010) has argued that climate change will lead to human rights violations specifically in relation to the Inuit people of the Arctic and that this requires consideration by parties under the terms of Article 2 of the UNFCCC. Kittel et al. (2010) provide an insight into the profound changes in the Alaskan landscape and ecosystems that have been observed in the past 50 years, including by the Inuit people, driven by warming, permafrost thaw and sea-ice thinning and that are projected to accelerate the future. Whilst legally unclear in the context of the UNFCCC, the impacts of climate change on indigenous people and communities, particularly in polar and mountain regions was recognized as a key vulnerability in the IPCC AR4 assessment.

Why is defining the ultimate objective of climate policy important?

The large inertia in parts of the climate system and in socio-economic systems implies the need, long recognized, for decision-making on levels of mitigation far ahead of the time at which full certainty on the impacts of climate change would be achieved (Nordhaus 1977). It is therefore necessary to decide on the climate risks that are to be minimized or prevented in order to be able to actively manage other unavoidable emerging risks. Not deciding on what levels of risks to take, could in effect, be deciding to take higher risks given that large amounts of warming and sea-level rise would be irreversibly committed from emissions that might otherwise have been avoided (Friedlingstein and Solomon 2005; Wigley 2005; Hare and Meinshausen 2006; Donner 2009). Following from this is the need to have quantitative guidance on emission pathways that are consistent with limiting risks, and hence on the required mitigation and adaptation tasks that need to be planned for. Decisions made in relation to Article 2 (or not made) would determine the level of climate change that is set as the goal for policy (or which is committed to as a consequence of lack of action), and these decisions have fundamental implications for emission reduction pathways and technological requirements as well as the scale of adaptation required.

The history of Article 2: attempts to define dangerous interference[2]

In 1985 at a meeting in Villach, Austria[3] an international gathering of scientists raised essentially for the first time the concern that projected human induced climate change would lead to unacceptable damages and changes to the earth, its ecosystems and to humans and human society. Since that time, several scientific assessment groups have sought to identify acceptable or tolerable limits to human induced climate change. There have been two broad approaches, often combined. One is based on a risk assessment using projected impacts of climate change on ecosystems, agriculture and other sectors. The other is based on a safe climate analogue approach which focuses on avoiding greater changes than are thought to have occurred in recent earth history (e.g., the current and the last few interglacial periods extending back half a million years or so). In this latter approach, the core idea is that tolerable human-induced changes are limited to those that would maintain the climate system within or close to a

[2] For the theme of this section see also the contribution of Jaeger and Jaeger (2010).

[3] http://www.icsu-scope.org/downloadpubs/scope29/statement.html.

state in terms of greenhouse gas concentrations which is not very different than the present interglacial and away from states associated with large or rapid changes in climate and/or components of the climate system such as the present ice sheets of Greenland and Antarctica.

One of the earliest attempts dating from the late 1980s to define acceptable limits to warming is that of the German *Enquetekommission*, a joint committee of Parliamentarians and scientists which set as a limit 0.1°C per decade as a level especially critical to forest ecosystems with an overall maximum warming of 1 or 2°C (Jain and Bach 1994).

One of the most important contributions was that of the UNEP/WMO/ICSU United Nations Advisory Group on Greenhouse Gases (AGGG) which was established in 1986 (Potter 1986). It reviewed the early climate impacts literature as well as what was known at that time about the behaviour of the climate system in the past. In its report in 1990, the AGGG combined both approaches to identify two main temperature indicators or thresholds with different levels of risk (Rijsberman and Swart 1990). The AGGG found that an increase of greater than 1°C above pre-industrial climate levels "may elicit rapid, unpredictable and non-linear responses that could lead to extensive ecosystem damage" and that warming rates above 0.1°C/decade were likely to lead to rapidly increasing risk of significant ecosystem damage. A 2°C increase was suggested by the AGGG to be "an upper limit beyond which the risks of grave damage to ecosystems, and of non-linear responses, are expected to increase rapidly". On sea-level rise, the AGGG argued that rates of sea-level rise of less than 20 mm/decade (20 cm/century) "would permit the vast majority of vulnerable ecosystems, such as natural wetlands and coral reefs to adapt with rates beyond this leading to rapidly rising ecosystem damage" and limiting total sea-level rise to a 50 cm increase above 1990 global mean sea level could "prevent the complete destruction of island nations, but would entail large increases in the societal and ecological damage caused by storms".

In the mid-1990s, the German Global Change Advisory Council (WBGU) determined an upper limit or "tolerable window" of warming based on a "top down" line of reasoning. It arrived at similar limit to the AGGG setting the tolerable warming limit of a 2°C increase relative to pre-industrial temperatures (WBGU 1995). Similar to the AGGG, it argued that above this limit there was a risk of "dramatic changes in the composition and function of today's ecosystems". This group confirmed this tolerable limit level in a subsequent assessment in 2003 which considered the question from a bottom up perspective based on a review of projected impacts (WBGU 2003). It was found that above 2°C the losses to species and ecosystems were "unacceptable" and that "above this global warming level worldwide climate-related losses in agricultural production must be expected", with "a steep rise in the number of people threatened by water scarcity." Ice sheet instability with consequential multi-metre sea-level rise was identified as a significant risk. It was recognized that "for some regions the effects of climate change would already lead to intolerable impacts at 2°C mean global warming". More recently, the WBGU, in the context of a review on the world's oceans, reconfirmed these goals and extended its tolerable limits, or guard rails, to sea-level rise where it recommended a long-term limit of 1 m with a maximum rate of 5 cm per decade, as "(o)therwise there is a high probability that human society and natural ecosystems will suffer unacceptable damage and loss" (WBGU 2006).

A group of largely US-based scientists (Hansen et al. 2007; Hansen et al. 2008) have also investigated the issue of what might be dangerous climate changes, whilst acknowledging that identification of this "is partly subjective". Several areas of risk were focused on—Increasing aridity in a number of regions (southern USA, parts of Africa, the Mediterranean basin and Australia), the stability of the ice sheets and long-term sea-level rise, Arctic sea-ice loss and warming, coral reefs, more intense tropical storms with increasing warming, and the likelihood of positive feedbacks amplifying warming due to the release of methane hydrates from the sea bed (which would add methane to the atmosphere, increasing the warming). Considering these issues they find that global warming of more than 1°C above 2000 "has effects that may be highly disruptive". This temperature limit with respect to 2000 translates into warming above pre-industrial of below 1.6–1.7°C, significantly lower than the 2°C "tolerable" limit identified by the WBGU. They indicated CO_2 levels need to be reduced to "at most 350 ppm, but likely less than that" and warned that if the over shoot of this level "is not brief, there is a possibility of seeding irreversible catastrophic effects". More recent research on the long-term response of ice sheets to warming and coral reefs tends to support at least these elements of the findings of Hansen and colleagues.

It is striking that the science-based assessments of what may be acceptable levels of human induced climate change have remained fairly stable over the last 20 years when expressed in terms of a global temperature limit. Different groups of scientists have successively found that between 1° and 2°C global mean warming above pre-industrial risks rise substantially, to the point where a level of non-acceptability is reached at close too or even below 2°C warming. In many respects, each assessment has confirmed the broad picture of risks first identified in 1990 by the UNEP/WMO/ICSU AGGG.

Over the last 20 years, the Intergovernmental Panel on Climate Change has provided four full assessment reports as well as a number of supplementary and special assessments on specific issues on the area of climate change. By its

mandate, the IPCC does not produce recommendations on what may or may not be acceptable levels of human induced climate change, as it is required to produce policy relevant but not policy prescriptive assessments. These reports have nevertheless been vital inputs into governmental processes considering climate issues since 1990.

In 1996, the European Union, based on a consideration of the IPCC Second Assessment Report (SAR) which was adopted in 1995 (IPCC 1996), agreed a global goal of ensuring that temperatures do not exceed 2°C increase above pre-industrial (European Community 1996). This was reconfirmed by the EU Environment Council in 2005 (Environment Council of the European Union 2005) following consideration of the IPCC Third Assessment Report of 2001, and subsequently adopted by the 25 heads of government of the European Union (ENDS 2005; European Union 2005). The so-called 2°C goal became one of the planks of the European Union's domestic and international policy, guiding both domestic reduction plans and international diplomatic efforts. In the lead up to the Copenhagen negotiations in 2009, the 2°C goal was adopted by the Major Economies Forum as well as by the G8 leaders meeting in that year (G8 2009; Major Economies Forum 2009).

The conclusion of the IPCC AR4 in 2007 spurred consideration by the small island states and other vulnerable countries of the merits of the EU's 2°C goal, as for these countries the AR4 had indicated substantial risk at lower levels of warming. Influenced by this assessment, and a number of the publications by scientific groups mentioned above, as well as growing evidence of impacts, in 2008 the Alliance of Small Island States (AOSIS) began calling for global temperature to be limited to below 1.5° increase above pre-industrial levels and the CO_2 concentrations to be brought below 350 ppm as fast as possible. AOSIS argued that the EU 2°C goal was unacceptable due to the damage that would be delivered to small island states at this level of warming. In the course of 2009, the least developed country group and others also began calling for warming to be limited to below a 1.5°C increase above pre-industrial based on similar considerations. By the time of UNFCCC Conference of the Parties (COP15) in Copenhagen, December 2009 a total of 101 countries, accounting for 5% of global energy and industry related CO_2 emissions and about 23% of global population in 2005[4] were calling for this goal to be adopted.

Both of these goals were reflected in the Copenhagen Accord, which was negotiated as part of a closed negotiating segment by 26 nations mostly at head of government level at COP15 and hence only 'taken note of' by the Conference of Parties. The Accord agreed "that deep cuts in global emissions are required according to science, […] with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius[5]" and hereby preventing "dangerous anthropogenic interference with the climate system". The goal of limiting warming to 1.5°C is referenced in association with potentially strengthening the 2°C long-term temperature goal based on "various matters presented by the science" in 2015. As of November 2010, a total of 140 countries have expressed their intention to be listed as "agreeing" with the Accord.[6]

Although the Copenhagen Accord is not a legal agreement as such, it does represent an important political interpretation at head of government level of the meaning of Article 2 of the climate change convention. It was concluded at Head of Government level and it specifically references the objective of preventing dangerous interference with the climate system. It is also clear that the emission pledges made by Parties to date under the Accord are not consistent with the 2° or 1.5°C goals (Rogelj et al. 2010a, b).

New findings relevant to Article 2

The papers in this special issue all tend to confirm the picture of regional risks and vulnerabilities in a range of regions and systems around the world as reported in the IPCC Fourth Assessment Report. There are several new developments, however, which will be highlighted here.

Food production

In relation to food production, the papers in this volume confirm earlier studies showing that climate change will induce strong contrasts between world regions, by causing yield increases in some and decreases in others, to an extent that is not easily solved by international markets (e.g., Battisti and Naylor 2009; Penny et al. 2010). Significant risks to food and water security are indicated for

[4] Those countries calling for global temperature to stay below 2°C comprise together a total of 46 countries, accounting for 83% of global energy and industry related CO_2 and about 65% of global population in 2005 Sources: Emissions—PRIMAP Baseline Reference: PRIMAP3 (2009) Potsdam Real-time Integrated Model for probabilistic Assessment of emissions Paths (PRIMAP), http://www.primap.org. Population—UN (2008) 'World Population Prospects: The 2008 Revision Population Database', http://esa.un.org/unpp.

[5] The Copenhagen Accord does not reference these increases to pre-industrial or any other base year or period. The interpretation applied here is that this is a drafting oversight as there was no other target on the table apart from the 2° and 1.5°C increases above pre-industrial and there is no evidence that the pre-industrial reference period was removed for any specific reason or at the request of any party.

[6] http://unfccc.int/home/items/5262.php accessed 18 November 2010.

South Asia (Lal 2010; Mirza 2010), Sahelian and northern Africa (Sissoko et al. 2010), Ben Mohamed (2010), Mougou et al. (2010), Iglesias et al. (2010) and parts of Russia (Dronin and Kirilenko 2010) by the time global mean warming reaches around 2°C above pre-industrial.

Lal (2010) shows that India needs to increase its production by 1.5% per year to feed its developing and growing population, faster than historical experience, but faces likely net cereal production losses in South Asia due to climate change of 4–10% for a 2°C warming. Lal (2010) further argues that warming above 3°C could have catastrophic consequences. Mirza (2010) shows a rapidly increasing risk for Bangladesh as warming rises towards 2°C, due to flooding, with losses plateauing as flooded area stabilizes, at a time that Bangladesh is projected to need to increase grain production by 3% per year (historically 2%/year).

In contrast to European Mediterranean countries that are expected to be able to cope with drought trends in the larger context of EU agricultural policy (Bindi and Olesen 2010), Iglesias et al. (2010) lay bare the very low adaptive capacity of African Mediterranean countries that will be confronted with increased drought and associated yield reductions. In the Sahel region, Sissoko et al. (2010) explain how existing coping strategies may break down under the pressures of future development in the context of yield decreases, confirmed by Ben Mohamed (2010), who report a projected loss in yields of millet, a major staple crop in the region, of 20% around 2°C warming, rising to 40% at about 3°C. The picture for parts of the African region covered in this issue is consistent with recent reviews, which indicate quite large negative impacts on food production at levels of warming lower than 2°C above pre-industrial (Burke et al. 2009; Schlenker and Lobell 2010). As discussed by Scheffran and Battaglini (2010), the pressure created by projected climate change seems likely to lead to increasing conflicts and their causalities. Sutton et al. (2010) suggest that projected climate change effects could cause civil wars in Africa by the 2030s (warming at this time would likely be below 1.5°C above pre-industrial).

Finally, Dronin and Kirilenko (2010) show that the existing administrative and institutional, as well as physical infrastructure in Russia will likely cause large problems for maintaining national food security and has historically contributed to famine in periods of drought. In Australia, (Steffen et al. 2010) show producers and industries operate from a long experience of coping with highly variable climate, but identified two climatic features that the sector is highly vulnerable to: abrupt climate shifts and intensifying droughts (see Risbey 2010). They point to the adaptive capacity of producers and industry as an important factor in determining what may be dangerous changes and argue that this sector has shown high adaptive capacity in the past and is beginning to adapt to changed climate variability now.

The IPCC AR4 assessment indicated that food production at the global level will probably be sufficient to feed the growing world population in the coming decades taking into account the projected effects of climate change. Observed negative effects of climate change on crop production in some regions (Auffhammer et al. 2006; Lobell and Field 2007) and new assessments of projections and uncertainties in relation to the role of CO_2 fertilization indicate a risk that global food production could be under more pressure from climate change than previously estimated (Lobell and Field 2008; Leakey 2009; Nelson et al. 2009; Rost et al. 2009; Schlenker and Roberts 2009).

What emerges from the papers in this issue is the danger of a widespread deterioration of regional food security in the 21st century under climate change for warming levels in the 1.5–2°C range. Many refer to the low adaptive capacity in some regions. Indeed, the most salient picture emerging from the papers in this issue on agriculture impacts is that highly challenging large-scale changes are required in regional specialization of food production, trade policies, development planning and water management for the regions discussed to have any chance of maintaining food security in the coming decades given global warming projections.

Arctic sea-ice loss, iconic species and loss of human cultures

Loss of Arctic sea ice and its consequential effects on ice-based ecosystems and the Arctic marine environment are described by Johannessen and Miles (2010). An accelerating loss of Arctic summer sea ice and volume has been observed over the last 50 years amounting to a 50% decline (Serreze et al. 2007; Stroeve et al. 2007; Stroeve et al. 2008; Lindsay et al. 2009; Markus et al. 2009; Simmonds and Keay 2009), with losses occurring faster than predicted by models (Boe et al. 2009). Whereas the IPCC AR4 assessment indicated almost complete loss of late summer sea ice for some scenarios by the latter part of the 21st century, more recent projections indicate that this could occur as early as the 2030s (Wang and Overland 2009; Zhang 2010). Johannessen and Miles in (2010) estimate loss by the 2050s, but in any event by the latter half of the 21st century (Boe et al. 2009).

The consequences for Arctic sea ice-based systems and species are serious (Johannessen and Miles 2010) with increasing loss of summer sea-ice extent and volume likely to push polar bears, walrus, some Arctic sea birds and seals to extinction. The IPCC AR4 indicated that the Polar bear

(*Ursus maritimus*) faces a high risk of extinction with global warming in the range 2.5–3.0°C above pre-industrial based in the model projections then available, which projected a multi-model mean 62% (range 40–100%) loss of Arctic summer ice extent (Fischlin et al. 2007). With such losses projected now to occur at substantially lower temperatures (ca 1.5–2.0°C), the extinction risk for this iconic species appears to be very high within the next half century. Detailed population-based observations (Schliebe et al. 2008; Stirling et al. 2008; Regehr et al. 2010; Rode et al. 2010) and projections (Durner et al. 2009; Hunter et al. 2010) confirm this inference.

Loss of unique and vulnerable polar communities was recognized as a key vulnerability in the IPCC AR4 (IPCC 2007; Schneider et al. 2007). Crowley (2010) makes a case for consideration of the loss of unique cultures, in this case the Inuit of the Arctic, as a basis for determining what is dangerous under Article 2: if it were to be accepted it could imply an even lower warming limit than 1.5°C.

Large-scale sea-level rise

There have been significant developments in the projection of sea-level rise, which affects a number of the regions reviewed in this special issue. Recent studies (Rahmstorf 2007; Pfeffer et al. 2008; Rohling et al. 2008; Vermeer and Rahmstorf 2009) indicate that sea-level rise over the next century is likely to be significantly higher than the estimates in the IPCC AR4.[7] The accelerating loss of ice from the Greenland and Antarctic ice sheets, which is occurring at a rate faster than previously predicted, was not able to be accounted for in the AR4 estimates of 20–60 cm above 1990 levels by the end of the 21st century. New projections based on the observed relationship between sea level and temperature (Rahmstorf 2007; Vermeer and Rahmstorf 2009) estimate a sea-level rise of 0.5–1.4 m above 1990 levels by 2100 for a warming range of 2–6°C above pre-industrial levels by 2100.

Recent research on the relationship between Antarctic temperatures and global sea level over the last 520,000 years indicates that multi-metre increases in sea level over the next centuries from warming levels of only 2°C are very likely due to the loss of ice from the ice sheets (Rohling et al. 2009). Evidence from a previous climatic warm period (119,000–124,000 years ago, when the climate warmed to around present levels and a bit higher) shows that rapid sea-level rise caused by melting or disintegration of the ice sheets has occurred before. During that period, sea levels stood at 4–6 metres higher than at present, and the rates of sea-level rise averaged 1.6 m/century (Rohling et al. 2008). Recent examination of plausible melting and/or disintegration rates for the ice sheets suggest strongly that a metre or more is possible if not likely by 2100 and that two metres cannot be ruled out (Pfeffer et al. 2008). Sea-level rise of a few metres could result in widespread loss of coastal and deltaic areas such as Bangladesh, the Nile, Yangtze and Mekong Delta regions, as well as major losses for many small island countries.

In the nearer term, sea-level rise and increased water temperatures are projected to accelerate beach and coastal erosion and cause degradation of natural coastal defences, including mangroves and coral reefs. These would in turn impact negatively on water supply, fisheries productivity and tourism industries in many small island countries and other regions. Sea-level rise will exacerbate the impacts of more intense tropical cyclones predicted under global warming (IPCC 2007; Bender et al. 2010; Knutson et al. 2010) on infrastructure.

Sea-level rise of 0.5 m has been projected to result in the total number of people exposed to flooding risk in 136 port cities globally increasing by more than threefold to around 150 million people and the total value of assets exposed[8] could rise by more than a factor of 10 (Nicholls et al. 2008). The top 10 cities exposed in term of population by the 2070s were Kolkata, Mumbai, Dhaka, Guangzhou, Ho Chi Minh City, Shanghai, Bangkok, Rangoon, Miami and Hai Phòng. On an asset base, the most vulnerable cities were found to be Miami, Guangdong, Greater New York, Kolkata, Shanghai, Mumbai, Tianjin, Tokyo, Hong Kong and Bangkok (Nicholls et al. 2008). Mirza (2010) reports that Bangladesh could lose 10% of its area due to a sea-level rise of 45 cm, and other work has estimated a loss about 18% of land area for a 95 cm sea-level rise (World Bank 2000).

The risks linked to sea-level rise appear to qualify as a dangerous change and point towards warming levels significantly lower than 2°C above pre-industrial being needed to prevent dangerous interference with the climate system if this were defined as avoiding a sea-level rise significantly lower than a metre.

Finally, another large-scale risk to emerge strongly from this special issue and in particular the review by Hoegh-Guldberg (2010) is that of the likely massive loss of coral reefs, due to the effects of warming and an increased CO_2 concentration acidifying the worlds oceans. Coral reefs

[7] The IPCC's Fourth Assessment Report estimated that global warming of 1.7–7°C above pre-industrial levels (without mitigation) would raise sea-level rise by 20–60 cm above 1990 levels by the end of the 21st century. The accelerating loss of ice from the Greenland and Antarctic ice sheets, which is occurring at a rate much faster than previously predicted, was not able to be accounted for in the AR4 estimates.

[8] Whilst exposure to risk does not determine actual damage, it is a useful indication of the way in which risk is increasing with sea level rise and global warming as the world develops.

provide vital resources for many small island states and are highly sensitive to both warming and ocean acidification due to increased CO_2 concentrations.

High ocean temperatures have already started to trigger unprecedented mass coral bleaching events effecting entire reefs, regions and countries. The IPCC AR4 found that "Climate change is likely to heavily impact coral reefs, fisheries and other marine-based resources" (Mimura et al. 2007). With 1.5–2°C warming, widespread mortality of coral reefs was predicted (Fischlin et al. 2007). Since the IPCC AR4, scientific understanding of the risks to coral reefs has expanded substantially. Regionally, for example, projections based on IPCC AR4 climate model simulations indicate that severe thermal stress may become a biannual to annual event in the Eastern Caribbean by the 2020s or 2030s when global mean temperature is increased by about 1–1.5°C from pre-industrial levels (Donner et al. 2007).

The most significant findings, however, relate to the effect of ocean acidification (Hoegh-Guldberg 2010). As CO_2 concentration in the atmosphere rises, the oceans absorb more CO_2, increasing the acidity of the oceans. An increase in ocean acidity has already been reported by the IPCC (2007). Higher ocean acidity reduces the ability of coral species to sequester calcium, which is vitally required for growth and maintenance of coral reefs (Fischlin et al. 2007). Reduced reef calcification has been observed since 1990 in some regions (Cooper et al. 2008; De'ath et al. 2009; Tanzil et al. 2009).[9] It has been estimated that corals around the world are likely to stop growing once atmospheric CO_2 concentration climbs above about 450 ppm, and would start dissolving above 550 ppm CO_2 (Cao and Caldeira 2008; Silverman et al. 2009). Negative effects on the reproductive cycle of corals are also predicted (Albright et al. 2010).

These and other considerations lead Hoegh-Guldberg (2010), and others (Donner 2009; Veron et al. 2009) to conclude that the survival of coral reefs implies a need to reduce CO_2 concentration to 350 ppm or below. The warming limit for the viability of reefs appears to be substantially lower than a 2°C global mean warming, possibly lower than 1.5°C.

Conclusions

The examples from the literature described above can be used to define levels of climate change that would constitute dangerous anthropogenic interference with the climate system under Article 2 of the UNFCCC. In the eyes of many, they imply the need to limit both global mean warming and CO_2 concentration to levels, respectively, substantially lower than 2°C and likely below 1.5°C in the

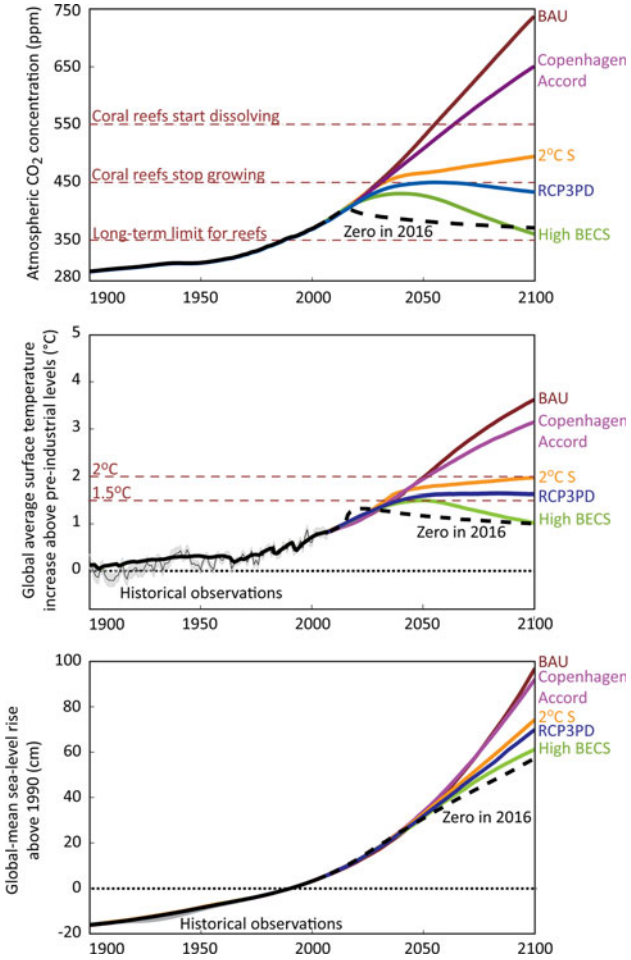


Fig. 1 Illustration of the effect of the current emissions reduction proposals under the Copenhagen Accord. Besides the pathways representing a business-as-usual scenario (BAU very close to SRES A1B, Nakicenovic et al. 2000) and the estimated emissions based on the Copenhagen Accord proposals (Rogelj et al. 2010a; Rogelj et al. 2010b), four low-emission pathways are shown. The *black dashed line* indicates the expected temperature projections if all global emissions (greenhouse gases and aerosols) would become zero in 2016. It therefore illustrates the global warming commitment due to emissions until 2015. The *green line* represents a scenario that reaches negative CO_2 emissions shortly after 2050, by implementing large-scale biomass energy systems combined with carbon capture and storage (BECS) at the high end of the potential range found in literature (e.g., Azar et al. 2006; van Vuuren et al. 2008; Knopf et al. 2010). RCP3PD (van Vuuren et al. 2008) is an illustrative low-emissions scenario technically and economically feasible at modest overall costs and which is to be used in the IPCC Fifth Assessment Report (AR5) as the lowest reference concentration profile. Finally, 2°C S represents an illustrative example of an emission pathway aimed at stabilizing global warming at 2°C above pre-industrial. Projections for CO_2 and temperature change follow models and method of Meinshausen et al. (2009). Sea-level rise projections follow models and method of Rahmstorf (2007). The median projections from these Monte-Carlo setups are shown here

[9] Although some corals might be able to adapt to temperature changes within certain limits, there is one recent study showing that this ability might be reduced under high CO_2 conditions: CO_2 could act as a bleaching agent and even lower thermal bleaching thresholds (Anthony et al. 2008).

longer term and below present levels of CO_2 concentration, likely below 350 ppm.

The emission pledges made under Copenhagen Accord are estimated to result in a warming of 3.3°C above pre-industrial within the 21st century (Rogelj et al. 2010a, b), substantially above the levels of warming identified here as possibly dangerous. In relation to the CO_2 concentration levels identified here as potentially dangerous, the Copenhagen Accord pledges imply that a CO_2 concentration of 450 ppm could be reached as early as the 2030s (Rogelj et al. 2010a, b). CO_2 concentration was about 278 ppm in pre-industrial times (mid-19th century) and as of the end of 2009 was around 387 ppmv[10] (Friedlingstein et al. 2010), above the 350 ppm level that may be appropriated for long-term coral reef survival. See Fig. 1 for an overview of scenario projections.

The emission pledges made under the Copenhagen Accord is, in view of the examples provided and the evidence collected in this special issue, insufficient to meet the terms of Article 2 of preventing dangerous climate change. More work needs to be done to further define and operationalize Article 2, but we need to accept that danger necessarily has a subjective dimension and that its definition requires judgment and precaution.

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Technical Support Document: -
Social Cost of Carbon for Regulatory Impact Analysis -
Under Executive Order 12866 -

Interagency Working Group on Social Cost of Carbon, United States Government

With participation by

Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of Transportation
Environmental Protection Agency
National Economic Council
Office of Energy and Climate Change
Office of Management and Budget
Office of Science and Technology Policy
Department of the Treasury

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Executive Summary

Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the "social cost of carbon" (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

This document presents a summary of the interagency process that developed these SCC estimates. Technical experts from numerous agencies met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

Discount Rate	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

I. Monetizing Carbon Dioxide Emissions

The "social cost of carbon" (SCC) is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. We report estimates of the social cost of carbon in dollars per metric ton of carbon dioxide throughout this document.[1]

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A recent report from the National Academies of Science (NRC 2009) points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to make it possible for agencies to incorporate the social benefits from reducing carbon dioxide emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. Most federal regulatory actions can be expected to have marginal impacts on global emissions.

For such policies, the benefits from reduced (or costs from increased) emissions in any future year can be estimated by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions. For policies that have a large (non-marginal) impact on global cumulative emissions, there is a separate question of whether the SCC is an appropriate tool for calculating the benefits of reduced emissions; we do not attempt to answer that question here.

An interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. Agencies that actively participated in the interagency process include the Environmental Protection

[1] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).

Agency, and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are $5, $21, $35, and $65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to $24 per ton of CO_2 in 2015 and $26 per ton of CO_2 in 2020. See Appendix A for the full range of annual SCC estimates from 2010 to 2050.

It is important to emphasize that the interagency process is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, we have set a preliminary goal of revisiting the SCC values within two years or at such time as substantially updated models become available, and to continue to support research in this area. In the meantime, we will continue to explore the issues raised in this document and consider public comments as part of the ongoing interagency process.

II. Social Cost of Carbon Values Used in Past Regulatory Analyses

To date, economic analyses for Federal regulations have used a wide range of values to estimate the benefits associated with reducing carbon dioxide emissions. In the final model year 2011 CAFE rule, the Department of Transportation (DOT) used both a "domestic" SCC value of $2 per ton of CO_2 and a "global" SCC value of $33 per ton of CO_2 for 2007 emission reductions (in 2007 dollars), increasing both values at 2.4 percent per year. It also included a sensitivity analysis at $80 per ton of CO_2. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

A 2008 regulation proposed by DOT assumed a domestic SCC value of $7 per ton CO_2 (in 2006 dollars) for 2011 emission reductions (with a range of $0-$14 for sensitivity analysis), also increasing at 2.4 percent per year. A regulation finalized by DOE in October of 2008 used a domestic SCC range of $0 to $20 per ton CO_2 for 2007 emission reductions (in 2007 dollars). In addition, EPA's 2008 Advance Notice of Proposed Rulemaking for Greenhouse Gases identified what it described as "very preliminary" SCC estimates subject to revision. EPA's global mean values were $68 and $40 per ton CO_2 for discount rates of approximately 2 percent and 3 percent, respectively (in 2006 dollars for 2007 emissions).

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted.

The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of $55, $33, $19, $10, and $5 per ton of CO_2. The $33 and $5 values represented model-weighted means of the published estimates produced from the most recently available versions of three integrated assessment models—DICE, PAGE, and FUND—at approximately 3 and 5 percent discount rates. The $55 and $10 values were derived by adjusting the published estimates for uncertainty in the discount rate (using factors developed by Newell and Pizer (2003)) at 3 and 5 percent discount rates, respectively. The $19 value was chosen as a central value between the $5 and $33 per ton estimates. All of these values were assumed to increase at 3 percent annually to represent growth in incremental damages over time as the magnitude of climate change increases.

These interim values represent the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules and were offered for public comment in connection with proposed rules, including the joint EPA-DOT fuel economy and CO_2 tailpipe emission proposed rules.

III. Approach and Key Assumptions

Since the release of the interim values, interagency group has reconvened on a regular basis to generate improved SCC estimates. Specifically, the group has considered public comments and further explored the technical literature in relevant fields. This section details the several choices and assumptions that underlie the resulting estimates of the SCC.

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Academy of Science (2009) points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. Throughout this document, we highlight a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC.

The U.S. Government will periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling. In this context, statements recognizing the limitations of the analysis and calling for further research take on exceptional significance. The interagency group offers the new SCC values with all due humility about the uncertainties embedded in them and with a sincere promise to continue work to improve them.

A. Integrated Assessment Models

We rely on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.[2] These models are frequently cited in the peer-reviewed literature and used in the IPCC assessment. Each model is given equal weight in the SCC values developed through this process, bearing in mind their different limitations (discussed below).

These models are useful because they combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single modeling framework. At the same time, they gain this advantage at the expense of a more detailed representation of the underlying climatic and economic systems. DICE, PAGE, and FUND all take stylized, reduced-form approaches (see NRC 2009 for a more detailed discussion; see Nordhaus 2008 on the possible advantages of this approach). Other IAMs may better reflect the complexity of the science in their modeling frameworks but do not link physical impacts to economic damages. There is currently a limited amount of research linking climate impacts to economic damages, which makes this exercise even more difficult. Underlying the three IAMs selected for this exercise are a number of simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize the available scientific and economic research characterizing these relationships.

The three IAMs translate emissions into changes in atmospheric greenhouse concentrations, atmospheric concentrations into changes in temperature, and changes in temperature into economic damages. The emissions projections used in the models are based on specified socio-economic (GDP and population) pathways. These emissions are translated into concentrations using the carbon cycle built into each model, and concentrations are translated into warming based on each model's simplified representation of the climate and a key parameter, climate sensitivity. Each model uses a different approach to translate warming into damages. Finally, transforming the stream of economic damages over time into a single value requires judgments about how to discount them.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. In PAGE, for example, the consumption-equivalent damages in each period are calculated as a fraction of GDP, depending on the temperature in that period relative to the pre-industrial average temperature in each region. In FUND, damages in each period also depend on the rate of temperature change from the prior period. In DICE, temperature affects both consumption and investment. We describe each model in greater detail here. In a later section, we discuss key gaps in how the models account for various scientific and economic processes (e.g. the probability of catastrophe, and the ability to adapt to climate change and the physical changes it causes).

[2] The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, originally to study international capital transfers in climate policy. is now widely used to study climate impacts (e.g., Tol 2002a, Tol 2002b, Anthoff et al. 2009, Tol 2009).

The parameters and assumptions embedded in the three models vary widely. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: climate sensitivity, socio-economic and emissions trajectories, and discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socio-economic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments. In DICE, these parameters are handled deterministically and represented by fixed constants; in PAGE, most parameters are represented by probability distributions. FUND was also run in a mode in which parameters were treated probabilistically.

The sensitivity of the results to other aspects of the models (e.g. the carbon cycle or damage function) is also important to explore in the context of future revisions to the SCC but has not been incorporated into these estimates. Areas for future research are highlighted at the end of this document.

The DICE Model

The DICE model is an optimal growth model based on a global production function with an extra stock variable (atmospheric carbon dioxide concentrations). Emission reductions are treated as analogous to investment in "natural capital." By investing in natural capital today through reductions in emissions—implying reduced consumption—harmful effects of climate change can be avoided and future consumption thereby increased.

For purposes of estimating the SCC, carbon dioxide emissions are a function of global GDP and the carbon intensity of economic output, with the latter declining over time due to technological progress. The DICE damage function links global average temperature to the overall impact on the world economy. It varies quadratically with temperature change to capture the more rapid increase in damages expected to occur under more extreme climate change, and is calibrated to include the effects of warming on the production of market and nonmarket goods and services. It incorporates impacts on agriculture, coastal areas (due to sea level rise), "other vulnerable market sectors" (based primarily on changes in energy use), human health (based on climate-related diseases, such as malaria and dengue fever, and pollution), non-market amenities (based on outdoor recreation), and human settlements and ecosystems. The DICE damage function also includes the expected value of damages associated with low probability, high impact "catastrophic" climate change. This last component is calibrated based on a survey of experts (Nordhaus 1994). The expected value of these impacts is then added to the other market and non-market impacts mentioned above.

No structural components of the DICE model represent adaptation explicitly, though it is included implicitly through the choice of studies used to calibrate the aggregate damage function. For example, its agricultural impact estimates assume that farmers can adjust land use decisions in response to changing climate conditions, and its health impact estimates assume improvements in healthcare over time. In addition, the small impacts on forestry, water systems, construction, fisheries, and outdoor recreation imply optimistic and costless adaptation in these sectors (Nordhaus and Boyer, 2000; Warren

et al., 2006). Costs of resettlement due to sea level rise are incorporated into damage estimates, but their magnitude is not clearly reported. Mastrandrea's (2009) review concludes that "in general, DICE assumes very effective adaptation, and largely ignores adaptation costs."

Note that the damage function in DICE has a somewhat different meaning from the damage functions in FUND and PAGE. Because GDP is endogenous in DICE and because damages in a given year reduce investment in that year, damages propagate forward in time and reduce GDP in future years. In contrast, GDP is exogenous in FUND and PAGE, so damages in any given year do not propagate forward.[3]

The PAGE Model

PAGE2002 (version 1.4epm) treats GDP growth as exogenous. It divides impacts into economic, non-economic, and catastrophic categories and calculates these impacts separately for eight geographic regions. Damages in each region are expressed as a fraction of output, where the fraction lost depends on the temperature change in each region. Damages are expressed as power functions of temperature change. The exponents of the damage function are the same in all regions but are treated as uncertain, with values ranging from 1 to 3 (instead of being fixed at 2 as in DICE).

PAGE2002 includes the consequences of catastrophic events in a separate damage sub-function. Unlike DICE, PAGE2002 models these events probabilistically. The probability of a "discontinuity" (i.e., a catastrophic event) is assumed to increase with temperature above a specified threshold. The threshold temperature, the rate at which the probability of experiencing a discontinuity increases above the threshold, and the magnitude of the resulting catastrophe are all modeled probabilistically.

Adaptation is explicitly included in PAGE. Impacts are assumed to occur for temperature increases above some tolerable level (2°C for developed countries and 0°C for developing countries for economic impacts, and 0°C for all regions for non-economic impacts), but adaptation is assumed to reduce these impacts. Default values in PAGE2002 assume that the developed countries can ultimately eliminate up to 90 percent of all economic impacts beyond the tolerable 2°C increase and that developing countries can eventually eliminate 50 percent of their economic impacts. All regions are assumed to be able to mitigate 25 percent of the non-economic impacts through adaptation (Hope 2006).

The FUND Model

Like PAGE, the FUND model treats GDP growth as exogenous. It includes separately calibrated damage functions for eight market and nonmarket sectors: agriculture, forestry, water, energy (based on heating and cooling demand), sea level rise (based on the value of land lost and the cost of protection),

[3] Using the default assumptions in DICE 2007, this effect generates an approximately 25 percent increase in the SCC relative to damages calculated by fixing GDP. In DICE2007, the time path of GDP is endogenous. Specifically, the path of GDP depends on the rate of saving and level of abatement in each period chosen by the optimizing representative agent in the model. We made two modifications to DICE to make it consistent with EMF GDP trajectories (see next section): we assumed a fixed rate of savings of 20%, and we re-calibrated the exogenous path of total factor productivity so that DICE would produce GDP projections in the absence of warming that exactly matched the EMF scenarios.

ecosystems, human health (diarrhea, vector-borne diseases, and cardiovascular and respiratory mortality), and extreme weather. Each impact sector has a different functional form, and is calculated separately for sixteen geographic regions. In some impact sectors, the fraction of output lost or gained due to climate change depends not only on the absolute temperature change but also on the rate of temperature change and level of regional income.[4] In the forestry and agricultural sectors, economic damages also depend on CO_2 concentrations.

Tol (2009) discusses impacts not included in FUND, noting that many are likely to have a relatively small effect on damage estimates (both positive and negative). However, he characterizes several omitted impacts as "big unknowns": for instance, extreme climate scenarios, biodiversity loss, and effects on economic development and political violence. With regard to potentially catastrophic events, he notes, "Exactly what would cause these sorts of changes or what effects they would have are not well-understood, although the chance of any one of them happening seems low. But they do have the potential to happen relatively quickly, and if they did, the costs could be substantial. Only a few studies of climate change have examined these issues."

Adaptation is included both implicitly and explicitly in FUND. Explicit adaptation is seen in the agriculture and sea level rise sectors. Implicit adaptation is included in sectors such as energy and human health, where wealthier populations are assumed to be less vulnerable to climate impacts. For example, the damages to agriculture are the sum of three effects: (1) those due to the rate of temperature change (damages are always positive); (2) those due to the level of temperature change (damages can be positive or negative depending on region and temperature); and (3) those from CO_2 fertilization (damages are generally negative but diminishing to zero).

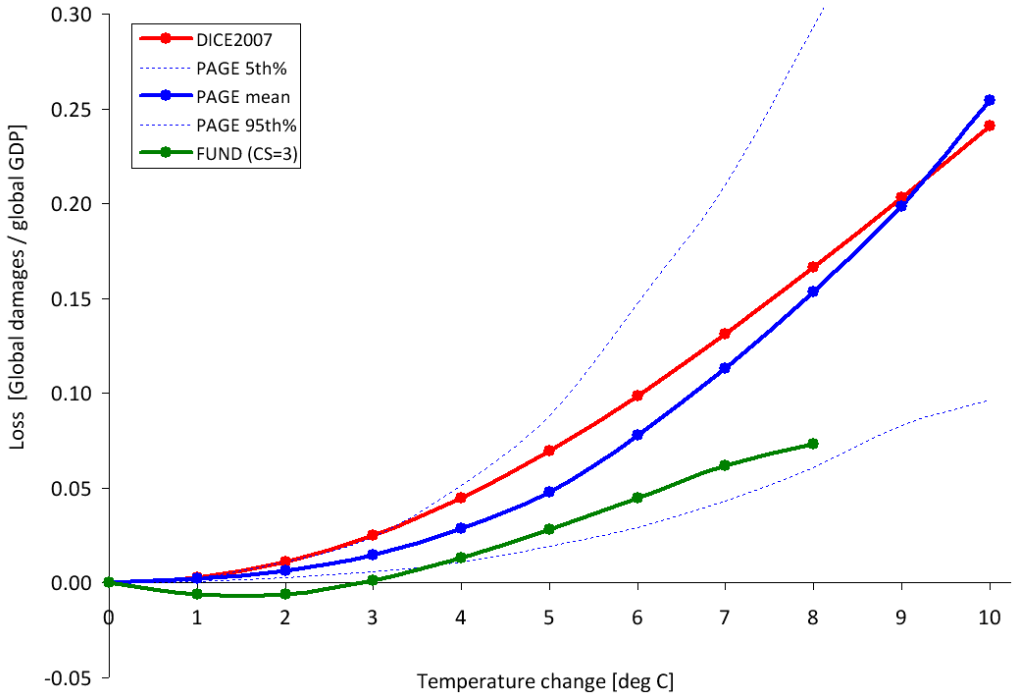
Adaptation is incorporated into FUND by allowing damages to be smaller if climate change happens more slowly. The combined effect of CO_2 fertilization in the agricultural sector, positive impacts to some regions from higher temperatures, and sufficiently slow increases in temperature across these sectors can result in negative economic damages from climate change.

Damage Functions

To generate revised SCC values, we rely on the IAM modelers' current best judgments of how to represent the effects of climate change (represented by the increase in global-average surface temperature) on the consumption-equivalent value of both market and non-market goods (represented as a fraction of global GDP). We recognize that these representations are incomplete and highly uncertain. But given the paucity of data linking the physical impacts to economic damages, we were not able to identify a better way to translate changes in climate into net economic damages, short of launching our own research program.

[4] In the deterministic version of FUND, the majority of damages are attributable to increased air conditioning demand, while reduced cold stress in Europe, North America, and Central and East Asia results in health benefits in those regions at low to moderate levels of warming (Warren et al., 2006).

Figure 1A: Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual - Global Temperature in the DICE, FUND, and PAGE models[5]



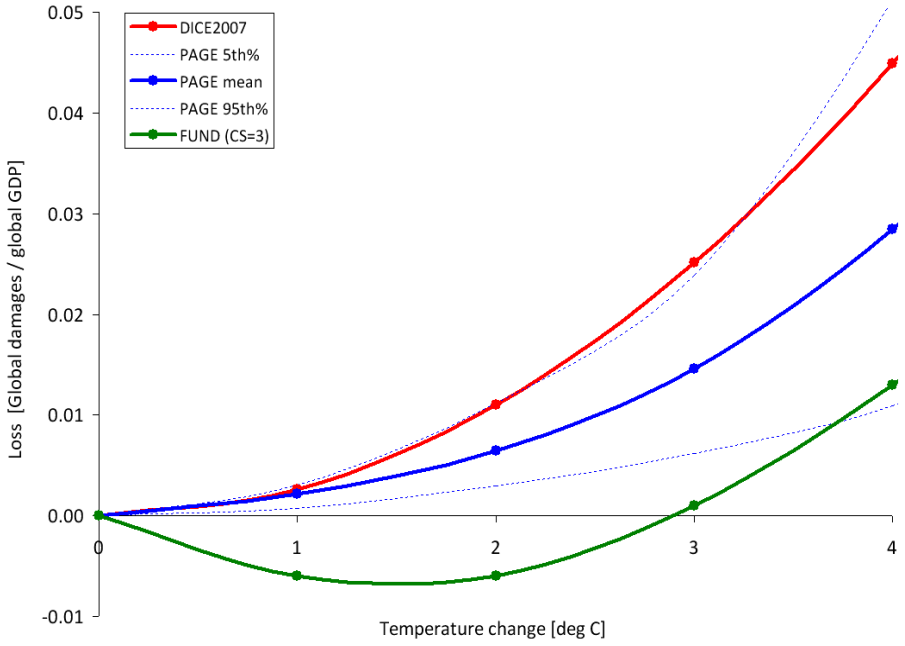
The damage functions for the three IAMs are presented in Figures 1A and 1B, using the modeler's default scenarios and mean input assumptions. There are significant differences between the three models both at lower (figure 1B) and higher (figure 1A) increases in global-average temperature.

The lack of agreement among the models at lower temperature increases is underscored by the fact that the damages from FUND are well below the 5th percentile estimated by PAGE, while the damages estimated by DICE are roughly equal to the 95th percentile estimated by PAGE. This is significant because at higher discount rates we expect that a greater proportion of the SCC value is due to damages in years with lower temperature increases. For example, when the discount rate is 2.5 percent, about 45 percent of the 2010 SCC value in DICE is due to damages that occur in years when the temperature is less than or equal to 3 °C. This increases to approximately 55 percent and 80 percent at discount rates of 3 and 5 percent, respectively.

These differences underscore the need for a thorough review of damage functions—in particular, how the models incorporate adaptation, technological change, and catastrophic damages. Gaps in the literature make modifying these aspects of the models challenging, which highlights the need for additional research. As knowledge improves, the Federal government is committed to exploring how these (and other) models can be modified to incorporate more accurate estimates of damages.

[5] The x-axis represents increases in annual, rather than equilibrium, temperature, while the y-axis represents the annual stream of benefits as a share of global GDP. Each specific combination of climate sensitivity, socio-economic, and emissions parameters will produce a different realization of damages for each IAM. The damage functions represented in Figures 1A and 1B are the outcome of default assumptions. For instance, under alternate assumptions, the damages from FUND may cross from negative to positive at less than or greater than 3 °C.

Figure 1B: Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE -



B. Global versus Domestic Measures of SCC

Because of the distinctive nature of the climate change problem, we center our current attention on a global measure of SCC. This approach is the same as that taken for the interim values, but it otherwise represents a departure from past practices, which tended to put greater emphasis on a domestic measure of SCC (limited to impacts of climate change experienced within U.S. borders). As a matter of law, consideration of both global and domestic values is generally permissible; the relevant statutory provisions are usually ambiguous and allow selection of either measure.[6]

Global SCC

Under current OMB guidance contained in Circular A-4, analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the climate change problem is highly unusual in at least two respects. First, it involves a global externality: emissions of most greenhouse gases contribute to damages around the world even when they are emitted in the United States. Consequently, to address the global nature of the problem, the SCC must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Even if the United States were to reduce its greenhouse gas emissions to zero, that step would be far from enough to avoid substantial climate change. Other countries would also need to take action to reduce emissions if

[6] It is true that federal statutes are presumed not to have extraterritorial effect, in part to ensure that the laws of the United States respect the interests of foreign sovereigns. But use of a global measure for the SCC does not give extraterritorial effect to federal law and hence does not intrude on such interests.

significant changes in the global climate are to be avoided. Emphasizing the need for a global solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions and in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. When these considerations are taken as a whole, the interagency group concluded that a global measure of the benefits from reducing U.S. emissions is preferable.

When quantifying the damages associated with a change in emissions, a number of analysts (e.g., Anthoff, et al. 2009a) employ "equity weighting" to aggregate changes in consumption across regions. This weighting takes into account the relative reductions in wealth in different regions of the world. A per-capita loss of $500 in GDP, for instance, is weighted more heavily in a country with a per-capita GDP of $2,000 than in one with a per-capita GDP of $40,000. The main argument for this approach is that a loss of $500 in a poor country causes a greater reduction in utility or welfare than does the same loss in a wealthy nation. Notwithstanding the theoretical claims on behalf of equity weighting, the interagency group concluded that this approach would not be appropriate for estimating a SCC value used in domestic regulatory analysis.[7] For this reason, the group concluded that using the global (rather than domestic) value, without equity weighting, is the appropriate approach.

Domestic SCC

As an empirical matter, the development of a domestic SCC is greatly complicated by the relatively few region- or country-specific estimates of the SCC in the literature. One potential source of estimates comes from the FUND model. The resulting estimates suggest that the ratio of domestic to global benefits of emission reductions varies with key parameter assumptions. For example, with a 2.5 or 3 percent discount rate, the U.S. benefit is about 7-10 percent of the global benefit, on average, across the scenarios analyzed. Alternatively, if the fraction of GDP lost due to climate change is assumed to be similar across countries, the domestic benefit would be proportional to the U.S. share of global GDP, which is currently about 23 percent.[8]

On the basis of this evidence, the interagency workgroup determined that a range of values from 7 to 23 percent should be used to adjust the global SCC to calculate domestic effects. Reported domestic values should use this range. It is recognized that these values are approximate, provisional, and highly speculative. There is no a priori reason why domestic benefits should be a constant fraction of net global damages over time. Further, FUND does not account for how damages in other regions could affect the United States (e.g., global migration, economic and political destabilization). If more accurate methods for calculating the domestic SCC become available, the Federal government will examine these to determine whether to update its approach.

[7] It is plausible that a loss of $X inflicts more serious harm on a poor nation than on a wealthy one, but development of the appropriate "equity weight" is challenging. Emissions reductions also impose costs, and hence a full account would have to consider that a given cost of emissions reductions imposes a greater utility or welfare loss on a poor nation than on a wealthy one. Even if equity weighting—for both the costs and benefits of emissions reductions—is appropriate when considering the utility or welfare effects of international action, the interagency group concluded that it should not be used in developing an SCC for use in regulatory policy at this time.

[8] Based on 2008 GDP (in current US dollars) from the *World Bank Development Indicators Report*.

C. Valuing Non-CO_2 Emissions

While CO_2 is the most prevalent greenhouse gas emitted into the atmosphere, the U.S. included five other greenhouse gases in its recent endangerment finding: methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The climate impact of these gases is commonly discussed in terms of their 100-year global warming potential (GWP). GWP measures the ability of different gases to trap heat in the atmosphere (i.e., radiative forcing per unit of mass) over a particular timeframe relative to CO_2. However, because these gases differ in both radiative forcing and atmospheric lifetimes, their relative damages are not constant over time. For example, because methane has a short lifetime, its impacts occur primarily in the near term and thus are not discounted as heavily as those caused by longer-lived gases. Impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Likewise, damages from methane emissions are not offset by the positive effect of CO_2 fertilization. Thus, transforming gases into CO_2-equivalents using GWP, and then multiplying the carbon-equivalents by the SCC, would not result in accurate estimates of the social costs of non-CO_2 gases.

In light of these limitations, and the significant contributions of non-CO_2 emissions to climate change, further research is required to link non-CO_2 emissions to economic impacts. Such work would feed into efforts to develop a monetized value of reductions in non-CO_2 greenhouse gas emissions. As part of ongoing work to further improve the SCC estimates, the interagency group hopes to develop methods to value these other greenhouse gases. The goal is to develop these estimates by the time we issue revised SCC estimates for carbon dioxide emissions.

D. Equilibrium Climate Sensitivity

Equilibrium climate sensitivity (ECS) is a key input parameter for the DICE, PAGE, and FUND models.[9] It is defined as the long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO_2 concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm)). Uncertainties in this important parameter have received substantial attention in the peer-reviewed literature.

The most authoritative statement about equilibrium climate sensitivity appears in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

> *Basing our assessment on a combination of several independent lines of evidence…including observed climate change and the strength of known feedbacks simulated in [global climate models], we conclude that the global mean equilibrium warming for doubling CO_2, or 'equilibrium climate*

[9] The equilibrium climate sensitivity includes the response of the climate system to increased greenhouse gas concentrations over the short to medium term (up to 100-200 years), but it does not include long-term feedback effects due to possible large-scale changes in ice sheets or the biosphere, which occur on a time scale of many hundreds to thousands of years (e.g. Hansen et al. 2007).

sensitivity', is likely to lie in the range 2 °C to 4.5 °C, with a most likely value of about 3 °C. Equilibrium climate sensitivity is very likely larger than 1.5 °C. [10]

For fundamental physical reasons as well as data limitations, values substantially higher than 4.5 °C still cannot be excluded, but agreement with observations and proxy data is generally worse for those high values than for values in the 2 °C to 4.5 °C range. (Meehl et al., 2007, p 799)

After consulting with several lead authors of this chapter of the IPCC report, the interagency workgroup selected four candidate probability distributions and calibrated them to be consistent with the above statement: Roe and Baker (2007), log-normal, gamma, and Weibull. Table 1 included below gives summary statistics for the four calibrated distributions.

Table 1: Summary Statistics for Four Calibrated Climate Sensitivity Distributions

	Roe & Baker	Log-normal	Gamma	Weibull
Pr(ECS < 1.5°C)	0.013	0.050	0.070	0.102
Pr(2°C < ECS < 4.5°C)	0.667	0.667	0.667	0.667
5th percentile	1.72	1.49	1.37	1.13
10th percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50th percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90th percentile	5.86	5.14	4.93	4.69
95th percentile	7.14	5.97	5.59	5.17

Each distribution was calibrated by applying three constraints from the IPCC:

(1) a median equal to 3°C, to reflect the judgment of "a most likely value of about 3 °C";[11]
(2) two-thirds probability that the equilibrium climate sensitivity lies between 2 and 4.5 °C; and
(3) zero probability that it is less than 0°C or greater than 10°C (see Hegerl et al. 2006, p. 721).

We selected the calibrated Roe and Baker distribution from the four candidates for two reasons. First, the Roe and Baker distribution is the only one of the four that is based on a theoretical understanding of the response of the climate system to increased greenhouse gas concentrations (Roe and Baker 2007,

[10] This is in accord with the judgment that it "is likely to lie in the range 2 °C to 4.5 °C" and the IPCC definition of "likely" as greater than 66 percent probability (Le Treut et al.2007). "Very likely" indicates a greater than 90 percent probability.

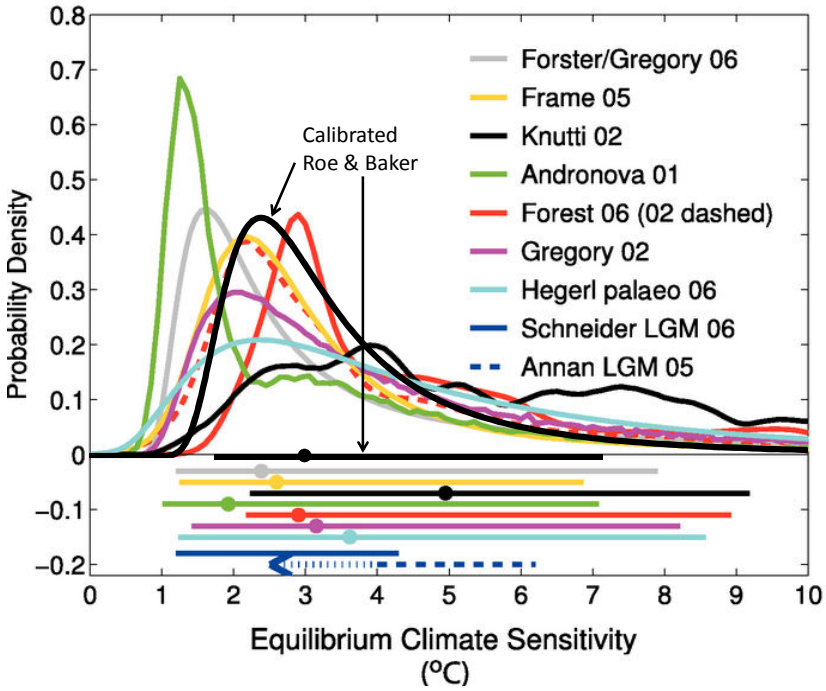
[11] Strictly speaking, "most likely" refers to the mode of a distribution rather than the median, but common usage would allow the mode, median, or mean to serve as candidates for the central or "most likely" value and the IPCC report is not specific on this point. For the distributions we considered, the median was between the mode and the mean. For the Roe and Baker distribution, setting the median equal to 3°C, rather than the mode or mean, gave a 95th percentile that is more consistent with IPCC judgments and the literature. For example, setting the mean and mode equal to 3°C produced 95th percentiles of 5.6 and 8.6 °C, respectively, which are in the lower and upper end of the range in the literature. Finally, the median is closer to 3°C than is the mode for the truncated distributions selected by the IPCC (Hegerl, et al., 2006); the average median is 3.1 °C and the average mode is 2.3 °C, which is most consistent with a Roe and Baker distribution with the median set equal to 3 °C.

Roe 2008). In contrast, the other three distributions are mathematical functions that are arbitrarily chosen based on simplicity, convenience, and general shape. The Roe and Baker distribution results from three assumptions about climate response: (1) absent feedback effects, the equilibrium climate sensitivity is equal to 1.2 °C; (2) feedback factors are proportional to the change in surface temperature; and (3) uncertainties in feedback factors are normally distributed. There is widespread agreement on the first point and the second and third points are common assumptions.

Second, the calibrated Roe and Baker distribution better reflects the IPCC judgment that "values substantially higher than 4.5°C still cannot be excluded." Although the IPCC made no quantitative judgment, the 95th percentile of the calibrated Roe & Baker distribution (7.1 °C) is much closer to the mean and the median (7.2 °C) of the 95th percentiles of 21 previous studies summarized by Newbold and Daigneault (2009). It is also closer to the mean (7.5 °C) and median (7.9 °C) of the nine truncated distributions examined by the IPCC (Hegerl, et al., 2006) than are the 95th percentiles of the three other calibrated distributions (5.2-6.0 °C).

Finally, we note the IPCC judgment that the equilibrium climate sensitivity "is very likely larger than 1.5°C." Although the calibrated Roe & Baker distribution, for which the probability of equilibrium climate sensitivity being greater than 1.5°C is almost 99 percent, is not inconsistent with the IPCC definition of "very likely" as "greater than 90 percent probability," it reflects a greater degree of certainty about very low values of ECS than was expressed by the IPCC.

Figure 2: Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)



To show how the calibrated Roe and Baker distribution compares to different estimates of the probability distribution function of equilibrium climate sensitivity in the empirical literature, Figure 2 (below) overlays it on Figure 9.20 from the IPCC Fourth Assessment Report. These functions are scaled

to integrate to unity between 0 °C and 10 °C. The horizontal bars show the respective 5 percent to 95 percent ranges; dots indicate the median estimate.[12]

E. Socio-Economic and Emissions Trajectories

Another key issue considered by the interagency group is how to select the set of socio-economic and emissions parameters for use in PAGE, DICE, and FUND. Socio-economic pathways are closely tied to climate damages because, all else equal, more and wealthier people tend to emit more greenhouse gases and also have a higher (absolute) willingness to pay to avoid climate disruptions. For this reason, we consider how to model several input parameters in tandem: GDP, population, CO_2 emissions, and non-CO_2 radiative forcing. A wide variety of scenarios have been developed and used for climate change policy simulations (e.g., SRES 2000, CCSP 2007, EMF 2009). In determining which scenarios are appropriate for inclusion, we aimed to select scenarios that span most of the plausible ranges of outcomes for these variables.

To accomplish this task in a transparent way, we decided to rely on the recent Stanford Energy Modeling Forum exercise, EMF-22. EMF-22 uses ten well-recognized models to evaluate substantial, coordinated global action to meet specific stabilization targets. A key advantage of relying on these data is that GDP, population, and emission trajectories are internally consistent for each model and scenario evaluated. The EMF-22 modeling effort also is preferable to the IPCC SRES due to their age (SRES were developed in 1997) and the fact that 3 of 4 of the SRES scenarios are now extreme outliers in one or more variables. Although the EMF-22 scenarios have not undergone the same level of scrutiny as the SRES scenarios, they are recent, peer-reviewed, published, and publicly available.

To estimate the SCC for use in evaluating domestic policies that will have a small effect on global cumulative emissions, we use socio-economic and emission trajectories that span a range of plausible scenarios. Five trajectories were selected from EMF-22 (see Table 2 below). Four of these represent potential business-as-usual (BAU) growth in population, wealth, and emissions and are associated with CO_2 (only) concentrations ranging from 612 to 889 ppm in 2100. One represents an emissions pathway that achieves stabilization at 550 ppm CO_2e (i.e., CO_2-only concentrations of 425 – 484 ppm or a radiative forcing of 3.7 W/m^2) in 2100, a lower-than-BAU trajectory.[13] Out of the 10 models included in the EMF-22 exercise, we selected the trajectories used by MiniCAM, MESSAGE, IMAGE, and the optimistic scenario from MERGE. For the BAU pathways, we used the GDP, population, and emission trajectories from each of these four models. For the 550 ppm CO_2e scenario, we averaged the GDP, population, and emission trajectories implied by these same four models.

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[12] The estimates based on instrumental data are from Andronova and Schlesinger (2001), Forest et al. (2002; dashed line, anthropogenic forcings only), Forest et al. (2006; solid line, anthropogenic and natural forcings), Gregory et al. (2002a), Knutti et al. (2002), Frame et al. (2005), and Forster and Gregory (2006). Hegerl et al. (2006) are based on multiple palaeoclimatic reconstructions of north hemisphere mean temperatures over the last 700 years. Also shown are the 5-95 percent approximate ranges for two estimates from the last glacial maximum (dashed, Annan et al. 2005; solid, Schneider von Deimling et al. 2006), which are based on models with different structural properties.

[13] Such an emissions path would be consistent with widespread action by countries to mitigate GHG emissions, though it could also result from technological advances. It was chosen because it represents the most stringent case analyzed by the EMF-22 where all the models converge: a 550 ppm, not to exceed, full participation scenario.

Table 2: Socioeconomic and Emissions Projections from Select EMF-22 Reference Scenarios -

Reference Fossil and Industrial CO_2 Emissions ($GtCO_2$/yr) -

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	26.6	31.9	36.9	40.0	45.3	60.1
MERGE Optimistic	24.6	31.5	37.6	45.1	66.5	117.9
MESSAGE	26.8	29.2	37.6	42.1	43.5	42.7
MiniCAM	26.5	31.8	38.0	45.1	57.8	80.5
550 ppm average	26.2	31.1	33.2	32.4	20.0	12.8

Reference GDP (using market exchange rates in trillion 2005$)[14]

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	38.6	53.0	73.5	97.2	156.3	396.6
MERGE Optimistic	36.3	45.9	59.7	76.8	122.7	268.0
MESSAGE	38.1	52.3	69.4	91.4	153.7	334.9
MiniCAM	36.1	47.4	60.8	78.9	125.7	369.5
550 ppm average	37.1	49.6	65.6	85.5	137.4	337.9

Global Population (billions)

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	6.1	6.9	7.6	8.2	9.0	9.1
MERGE Optimistic	6.0	6.8	7.5	8.2	9.0	9.7
MESSAGE	6.1	6.9	7.7	8.4	9.4	10.4
MiniCAM	6.0	6.8	7.5	8.1	8.8	8.7
550 ppm average	6.1	6.8	7.6	8.2	8.7	9.1

We explore how sensitive the SCC is to various assumptions about how the future will evolve without prejudging what is likely to occur. The interagency group considered formally assigning probability weights to different states of the world, but this proved challenging to do in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socio-economic pathways.

There are a number of caveats. First, EMF BAU scenarios represent the modelers' judgment of the most likely pathway absent mitigation policies to reduce greenhouse gas emissions, rather than the wider range of possible outcomes. Nevertheless, these views of the most likely outcome span a wide range,

[14] While the EMF-22 models used market exchange rates (MER) to calculate global GDP, it is also possible to use purchasing power parity (PPP). PPP takes into account the different price levels across countries, so it more accurately describes relative standards of living across countries. MERs tend to make low-income countries appear poorer than they actually are. Because many models assume convergence in per capita income over time, use of MER-adjusted GDP gives rise to projections of higher economic growth in low income countries. There is an ongoing debate about how much this will affect estimated climate impacts. Critics of the use of MER argue that it leads to overstated economic growth and hence a significant upward bias in projections of greenhouse gas emissions, and unrealistically high future temperatures (e.g., Castles and Henderson 2003). Others argue that convergence of the emissions-intensity gap across countries at least partially offset the overstated income gap so that differences in exchange rates have less of an effect on emissions (Holtsmark and Alfsen, 2005; Tol, 2006). Nordhaus (2007b) argues that the ideal approach is to use superlative PPP accounts (i.e., using cross-sectional PPP measures for relative incomes and outputs and national accounts price and quantity indexes for time-series extrapolations). However, he notes that it important to keep this debate in perspective; it is by no means clear that exchange-rate-conversion issues are as important as uncertainties about population, technological change, or the many geophysical uncertainties.

from the more optimistic (e.g. abundant low-cost, low-carbon energy) to more pessimistic (e.g. constraints on the availability of nuclear and renewables).[15] Second, the socio-economic trajectories associated with a 550 ppm CO_2e concentration scenario are not derived from an assessment of what policy is optimal from a benefit-cost standpoint. Rather, it is indicative of one possible future outcome. The emission trajectories underlying some BAU scenarios (e.g. MESSAGE's 612 ppm) also are consistent with some modest policy action to address climate change.[16] We chose not to include socio-economic trajectories that achieve even lower GHG concentrations at this time, given the difficulty many models had in converging to meet these targets.

For comparison purposes, the Energy Information Agency in its 2009 Annual Energy Outlook projected that global carbon dioxide emissions will grow to 30.8, 35.6, and 40.4 gigatons in 2010, 2020, and 2030, respectively, while world GDP is projected to be $51.8, $71.0 and $93.9 trillion (in 2005 dollars using market exchange rates) in 2010, 2020, and 2030, respectively. These projections are consistent with one or more EMF-22 scenarios. Likewise, the United Nations' 2008 Population Prospect projects population will grow from 6.1 billion people in 2000 to 9.1 billion people in 2050, which is close to the population trajectories for the IMAGE, MiniCAM, and MERGE models.

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane, nitrous oxide, fluorinated greenhouse gases, and net land use CO_2 emissions out to 2100. These assumptions also are used in the three models while retaining the default radiative forcings due to other factors (e.g. aerosols and other gases). See the Appendix for greater detail.

F. Discount Rate

The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law. Although it is well understood that the discount rate has a large influence on the current value of future damages, there is no consensus about what rates to use in this context. Because carbon dioxide emissions are long-lived, subsequent damages occur over many years. In calculating the SCC, we first estimate the future damages to agriculture, human health, and other market and non-market sectors from an additional unit of carbon dioxide emitted in a particular year in terms of reduced consumption (or consumption equivalents) due to the impacts of elevated temperatures, as represented in each of the three IAMs. Then we discount the stream of future damages to its present value in the year when the additional unit of emissions was released using the selected discount rate, which is intended to reflect society's marginal rate of substitution between consumption in different time periods.

For rules with both intra- and intergenerational effects, agencies traditionally employ constant discount rates of both 3 percent and 7 percent in accordance with OMB Circular A-4. As Circular A-4 acknowledges, however, the choice of discount rate for intergenerational problems raises distinctive

[15] For instance, in the MESSAGE model's reference case total primary energy production from nuclear, biomass, and non-biomass renewables is projected to increase from about 15 percent of total primary energy in 2000 to 54 percent in 2100. In comparison, the MiniCAM reference case shows 10 percent in 2000 and 21 percent in 2100.

[16] For example, MiniCAM projects if all non-US OECD countries reduce CO_2 emissions to 83 percent below 2005 levels by 2050 (per the G-8 agreement) but all other countries continue along a BAU path CO_2 concentrations in 2100 would drop from 794 ppmv in its reference case to 762 ppmv.

problems and presents considerable challenges. After reviewing those challenges, Circular A-4 states, "If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent." For the specific purpose of developing the SCC, we adapt and revise that approach here.

Arrow et al. (1996) outlined two main approaches to determine the discount rate for climate change analysis, which they labeled "descriptive" and "prescriptive." The descriptive approach reflects a positive (non-normative) perspective based on observations of people's actual choices—e.g., savings versus consumption decisions over time, and allocations of savings among more and less risky investments. Advocates of this approach generally call for inferring the discount rate from market rates of return "because of a lack of justification for choosing a social welfare function that is any different than what decision makers [individuals] actually use" (Arrow et al. 1996).

One theoretical foundation for the cost-benefit analyses in which the social cost of carbon will be used—the Kaldor-Hicks potential-compensation test—also suggests that market rates should be used to discount future benefits and costs, because it is the market interest rate that would govern the returns potentially set aside today to compensate future individuals for climate damages that they bear (e.g., Just et al. 2004). As some have noted, the word "potentially" is an important qualification; there is no assurance that such returns will actually be set aside to provide compensation, and the very idea of compensation is difficult to define in the intergenerational context. On the other hand, societies provide compensation to future generations through investments in human capital and the resulting increase in knowledge, as well as infrastructure and other physical capital.

The prescriptive approach specifies a social welfare function that formalizes the normative judgments that the decision-maker wants explicitly to incorporate into the policy evaluation—e.g., how inter-personal comparisons of utility should be made, and how the welfare of future generations should be weighed against that of the present generation. Ramsey (1928), for example, has argued that it is "ethically indefensible" to apply a positive pure rate of time preference to discount values across generations, and many agree with this view.

Other concerns also motivate making adjustments to descriptive discount rates. In particular, it has been noted that the preferences of future generations with regard to consumption versus environmental amenities may not be the same as those today, making the current market rate on consumption an inappropriate metric by which to discount future climate-related damages. Others argue that the discount rate should be below market rates to correct for market distortions and uncertainties or inefficiencies in intergenerational transfers of wealth, which in the Kaldor-Hicks logic are presumed to compensate future generations for damage (a potentially controversial assumption, as noted above) (Arrow et al. 1996, Weitzman 1999).

Further, a legitimate concern about both descriptive and prescriptive approaches is that they tend to obscure important heterogeneity in the population. The utility function that underlies the prescriptive approach assumes a representative agent with perfect foresight and no credit constraints. This is an artificial rendering of the real world that misses many of the frictions that characterize individuals' lives

and indeed the available descriptive evidence supports this. For instance, many individuals smooth consumption by borrowing with credit cards that have relatively high rates. Some are unable to access traditional credit markets and rely on payday lending operations or other high cost forms of smoothing consumption. Whether one puts greater weight on the prescriptive or descriptive approach, the high interest rates that credit-constrained individuals accept suggest that some account should be given to the discount rates revealed by their behavior.

We draw on both approaches but rely primarily on the descriptive approach to inform the choice of discount rate. With recognition of its limitations, we find this approach to be the most defensible and transparent given its consistency with the standard contemporary theoretical foundations of benefit-cost analysis and with the approach required by OMB's existing guidance. The logic of this framework also suggests that market rates should be used for discounting future consumption-equivalent damages. Regardless of the theoretical approach used to derive the appropriate discount rate(s), we note the inherent conceptual and practical difficulties of adequately capturing consumption trade-offs over many decades or even centuries. While relying primarily on the descriptive approach in selecting specific discount rates, the interagency group has been keenly aware of the deeply normative dimensions of both the debate over discounting in the intergenerational context and the consequences of selecting one discount rate over another.

Historically Observed Interest Rates

In a market with no distortions, the return to savings would equal the private return on investment, and the market rate of interest would be the appropriate choice for the social discount rate. In the real world risk, taxes, and other market imperfections drive a wedge between the risk-free rate of return on capital and the consumption rate of interest. Thus, the literature recognizes two conceptual discount concepts—the consumption rate of interest and the opportunity cost of capital.

According to OMB's Circular A-4, it is appropriate to use the rate of return on capital when a regulation is expected to displace or alter the use of capital in the private sector. In this case, OMB recommends Agencies use a discount rate of 7 percent. When regulation is expected to primarily affect private consumption—for instance, via higher prices for goods and services—a lower discount rate of 3 percent is appropriate to reflect how private individuals trade-off current and future consumption.

The interagency group examined the economics literature and concluded that the consumption rate of interest is the correct concept to use in evaluating the benefits and costs of a marginal change in carbon emissions (see Lind 1990, Arrow et al 1996, and Arrow 2000). The consumption rate of interest also is appropriate when the impacts of a regulation are measured in consumption (-equivalent) units, as is done in the three integrated assessment models used for estimating the SCC.

Individuals use a variety of savings instruments that vary with risk level, time horizon, and tax characteristics. The standard analytic framework used to develop intuition about the discount rate typically assumes a representative agent with perfect foresight and no credit constraints. The risk-free rate is appropriate for discounting certain future benefits or costs, but the benefits calculated by IAMs are uncertain. To use the risk-free rate to discount uncertain benefits, these benefits first must be

transformed into "certainty equivalents," that is the maximum certain amount that we would exchange for the uncertain amount. However, the calculation of the certainty-equivalent requires first estimating the correlation between the benefits of the policy and baseline consumption.

If the IAM projections of future impacts represent expected values (not certainty-equivalent values), then the appropriate discount rate generally does not equal the risk-free rate. If the benefits of the policy tend to be high in those states of the world in which consumption is low, then the certainty-equivalent benefits will be higher than the expected benefits (and vice versa). Since many (though not necessarily all) of the important impacts of climate change will flow through market sectors such as agriculture and energy, and since willingness to pay for environmental protections typically increases with income, we might expect a positive (though not necessarily perfect) correlation between the net benefits from climate policies and market returns. This line of reasoning suggests that the proper discount rate would exceed the riskless rate. Alternatively, a negative correlation between the returns to climate policies and market returns would imply that a discount rate below the riskless rate is appropriate.

This discussion suggests that both the post-tax riskless and risky rates can be used to capture individuals' consumption-equivalent interest rate. As a measure of the post-tax riskless rate, we calculate the average real return from Treasury notes over the longest time period available (those from Newell and Pizer 2003) and adjust for Federal taxes (the average marginal rate from tax years 2003 through 2006 is around 27 percent).[17] This calculation produces a real interest rate of about 2.7 percent, which is roughly consistent with Circular A-4's recommendation to use 3 percent to represent the consumption rate of interest.[18] A measure of the post-tax risky rate for investments whose returns are positively correlated with overall equity market returns can be obtained by adjusting pre-tax rates of household returns to risky investments (approximately 7 percent) for taxes yields a real rate of roughly 5 percent.[19]

The Ramsey Equation

Ramsey discounting also provides a useful framework to inform the choice of a discount rate. Under this approach, the analyst applies either positive or normative judgments in selecting values for the key parameters of the Ramsey equation: η (coefficient of relative risk aversion or elasticity of the marginal utility of consumption) and ρ (pure rate of time preference).[20] These are then combined with g (growth

[17] The literature argues for a risk-free rate on government bonds as an appropriate measure of the consumption rate of interest. Arrow (2000) suggests that it is roughly 3-4 percent. OMB cites evidence of a 3.1 percent pre-tax rate for 10-year Treasury notes in the A-4 guidance. Newell and Pizer (2003) find real interest rates between 3.5 and 4 percent for 30-year Treasury securities.

[18] The positive approach reflects how individuals make allocation choices across time, but it is important to keep in mind that we wish to reflect preferences for society as a whole, which generally has a longer planning horizon.

[19] Cambell et al (2001) estimates that the annual real return from stocks for 1900-1995 was about 7 percent. The annual real rate of return for the S&P 500 from 1950 – 2008 was about 6.8 percent. In the absence of a better way to population-weight the tax rates, we use the middle of the 20 – 40 percent range to derive a post-tax interest rate (Kotlikoff and Rapson 2006).

[20] The parameter ρ measures the *pure rate of time preference*: people's behavior reveals a preference for an increase in utility today versus the future. Consequently, it is standard to place a lower weight on utility in the future. The parameter η captures *diminishing marginal utility*: consumption in the future is likely to be higher than consumption today, so diminishing marginal utility of consumption implies that the same monetary damage will

rate of per-capita consumption) to equal the interest rate at which future monetized damages are discounted: $\rho + \eta \cdot g$.[21] In the simplest version of the Ramsey model, with an optimizing representative agent with perfect foresight, what we are calling the "Ramsey discount rate," $\rho + \eta \cdot g$, will be equal to the rate of return to capital, i.e., the market interest rate.

A review of the literature provides some guidance on reasonable parameter values for the Ramsey discounting equation, based on both prescriptive and descriptive approaches.

- η. Most papers in the climate change literature adopt values for η in the range of 0.5 to 3 (Weitzman cites plausible values as those ranging from 1 to 4), although not all authors articulate whether their choice is based on prescriptive or descriptive reasoning.[22] Dasgupta (2008) argues that η should be greater than 1 and may be as high as 3, since η equal to 1 suggests savings rates that do not conform to observed behavior.

- ρ. With respect to the pure rate of time preference, most papers in the climate change literature adopt values for ρ in the range of 0 to 3 percent per year. The very low rates tend to follow from moral judgments involving intergenerational neutrality. Some have argued that to use any value other than $\rho = 0$ would unjustly discriminate against future generations (e.g., Arrow et al. 1996, Stern et al. 2006). However, even in an inter-generational setting, it may make sense to use a small positive pure rate of time preference because of the small probability of unforeseen cataclysmic events (Stern et al. 2006).

- g. A commonly accepted approximation is around 2 percent per year. For the socio-economic scenarios used for this exercise, the EMF models assume that g is about 1.5-2 percent to 2100.

Some economists and non-economists have argued for constant discount rates below 2 percent based on the prescriptive approach. When grounded in the Ramsey framework, proponents of this approach have argued that a ρ of zero avoids giving preferential treatment to one generation over another. The choice of η has also been posed as an ethical choice linked to the value of an additional dollar in poorer

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cause a smaller reduction of utility for wealthier individuals, either in the future or in current generations. If $\eta = 0$, then a one dollar increase in income is equally valuable regardless of level of income; if $\eta = 1$, then a one percent increase in income is equally valuable no matter the level of income; and if $\eta > 1$, then a one percent increase in income is less valuable to wealthier individuals.

[21] In this case, g could be taken from the selected EMF socioeconomic scenarios or alternative assumptions about the rate of consumption growth.

[22] Empirical estimates of η span a wide range of values. A benchmark value of 2 is near the middle of the range of values estimated or used by Szpiro (1986), Hall and Jones (2007), Arrow (2007), Dasgupta (2006, 2008), Weitzman (2007, 2009), and Nordhaus (2008). However, Chetty (2006) developed a method of estimating η using data on labor supply behavior. He shows that existing evidence of the effects of wage changes on labor supply imposes a tight upper bound on the curvature of utility over wealth (CRRA < 2) with the mean implied value of 0.71 and concludes that the standard expected utility model cannot generate high levels of risk aversion without contradicting established facts about labor supply. Recent work has jointly estimated the components of the Ramsey equation. Evans and Sezer (2005) estimate $\eta = 1.49$ for 22 OECD countries. They also estimate $\rho = 1.08$ percent per year using data on mortality rates. Anthoff, et al. (2009b) estimate $\eta = 1.18$, and $\rho = 1.4$ percent. When they multiply the bivariate probability distributions from their work and Evans and Sezer (2005) together, they find $\eta = 1.47$, and $\rho = 1.07$.

countries compared to wealthier ones. Stern et al. (2006) applies this perspective through his choice of ρ = 0.1 percent per year, η = 1 and g = 1.3 percent per year, which yields an annual discount rate of 1.4 percent. In the context of permanent income savings behavior, however, Stern's assumptions suggest that individuals would save 93 percent of their income.[23]

Recently, Stern (2008) revisited the values used in Stern et al. (2006), stating that there is a case to be made for raising η due to the amount of weight lower values place on damages far in the future (over 90 percent of expected damages occur after 2200 with η = 1). Using Stern's assumption that ρ = 0.1 percent, combined with a η of 1.5 to 2 and his original growth rate, yields a discount rate greater 2 percent.

We conclude that arguments made under the prescriptive approach can be used to justify discount rates between roughly 1.4 and 3.1 percent. In light of concerns about the most appropriate value for η, we find it difficult to justify rates at the lower end of this range under the Ramsey framework.

Accounting for Uncertainty in the Discount Rate

While the consumption rate of interest is an important driver of the benefits estimate, it is uncertain over time. Ideally, we would formally model this uncertainty, just as we do for climate sensitivity. Weitzman (1998, 2001) showed theoretically and Newell and Pizer (2003) and Groom et al. (2006) confirm empirically that discount rate uncertainty can have a large effect on net present values. A main result from these studies is that if there is a persistent element to the uncertainty in the discount rate (e.g., the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time. Consequently, lower discount rates tend to dominate over the very long term (see Weitzman 1998, 1999, 2001; Newell and Pizer 2003; Groom et al. 2006; Gollier 2008; Summers and Zeckhauser 2008; and Gollier and Weitzman 2009).

The proper way to model discount rate uncertainty remains an active area of research. Newell and Pizer (2003) employ a model of how long-term interest rates change over time to forecast future discount rates. Their model incorporates some of the basic features of how interest rates move over time, and its parameters are estimated based on historical observations of long-term rates. Subsequent work on this topic, most notably Groom et al. (2006), uses more general models of interest rate dynamics to allow for better forecasts. Specifically, the volatility of interest rates depends on whether rates are currently low or high and variation in the level of persistence over time.

While Newell and Pizer (2003) and Groom et al (2006) attempt formally to model uncertainty in the discount rate, others argue for a declining scale of discount rates applied over time (e.g., Weitzman 2001, and the UK's "Green Book" for regulatory analysis). This approach uses a higher discount rate

[23] Stern (2008) argues that building in a positive rate of exogenous technical change over time reduces the implied savings rate and that η at or above 2 are inconsistent with observed behavior with regard to equity. (At the same time, adding exogenous technical change—all else equal—would increase g as well.)

initially, but applies a graduated scale of lower discount rates further out in time.[24] A key question that has emerged with regard to both of these approaches is the trade-off between potential time inconsistency and giving greater weight to far future outcomes (see the EPA Science Advisory Board's recent comments on this topic as part of its review of their *Guidelines for Economic Analysis*).[25]

The Discount Rates Selected for Estimating SCC

In light of disagreement in the literature on the appropriate market interest rate to use in this context and uncertainty about how interest rates may change over time, we use three discount rates to span a plausible range of certainty-equivalent constant discount rates: 2.5, 3, and 5 percent per year. Based on the review in the previous sections, the interagency workgroup determined that these three rates reflect reasonable judgments under both descriptive and prescriptive approaches.

The central value, 3 percent, is consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest. As previously mentioned, the consumption rate of interest is the correct discounting concept to use when future damages from elevated temperatures are estimated in consumption-equivalent units. Further, 3 percent roughly corresponds to the after-tax riskless interest rate. The upper value of 5 percent is included to represent the possibility that climate damages are positively correlated with market returns. Additionally, this discount rate may be justified by the high interest rates that many consumers use to smooth consumption across periods.

The low value, 2.5 percent, is included to incorporate the concern that interest rates are highly uncertain over time. It represents the average certainty-equivalent rate using the mean-reverting and random walk approaches from Newell and Pizer (2003) starting at a discount rate of 3 percent. Using this approach, the certainty equivalent is about 2.2 percent using the random walk model and 2.8 percent using the mean reverting approach.[26] Without giving preference to a particular model, the average of the two rates is 2.5 percent. Further, a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return. Use of this lower value also responds to certain judgments using the prescriptive or normative approach and to ethical objections that have been raised about rates of 3 percent or higher.

[24] For instance, the UK applies a discount rate of 3.5 percent to the first 30 years; 3 percent for years 31 - 75; 2.5 percent for years 76 - 125; 2 percent for years 126 - 200; 1.5 percent for years 201 - 300; and 1 percent after 300 years. As a sensitivity, it recommends a discount rate of 3 percent for the first 30 years, also decreasing over time.

[25] Uncertainty in future damages is distinct from uncertainty in the discount rate. Weitzman (2008) argues that Stern's choice of a low discount rate was "right for the wrong reasons." He demonstrates how the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. Newbold and Daigneault, (2009) and Nordhaus (2009) find that Weitzman's result is sensitive to the functional forms chosen for climate sensitivity, utility, and consumption. Summers and Zeckhauser (2008) argue that uncertainty in future damages can also work in the other direction by increasing the benefits of waiting to learn the appropriate level of mitigation required.

[26] Calculations done by Pizer et al. using the original simulation program from Newell and Pizer (2003).

IV. Revised SCC Estimates

Our general approach to estimating SCC values is to run the three integrated assessment models (FUND, DICE, and PAGE) using the following inputs agreed upon by the interagency group:

- A Roe and Baker distribution for the climate sensitivity parameter bounded between 0 and 10 with a median of 3 °C and a cumulative probability between 2 and 4.5 °C of two-thirds.
- Five sets of GDP, population and carbon emissions trajectories based on EMF-22.
- Constant annual discount rates of 2.5, 3, and 5 percent.

Because the climate sensitivity parameter is modeled probabilistically, and because PAGE and FUND incorporate uncertainty in other model parameters, the final output from each model run is a distribution over the SCC in year *t*.

For each of the IAMS, the basic computational steps for calculating the SCC in a particular year *t* are:

1. Input the path of emissions, GDP, and population from the selected EMF-22 scenarios, and the extrapolations based on these scenarios for post-2100 years.

2. Calculate the temperature effects and (consumption-equivalent) damages in each year resulting from the baseline path of emissions.

    a. In PAGE, the consumption-equivalent damages in each period are calculated as a fraction of the EMF GDP forecast, depending on the temperature in that period relative to the pre-industrial average temperature in each region.
    b. In FUND, damages in each period depend on both the level and the rate of temperature change in that period.
    c. In DICE, temperature affects both consumption and investment, so we first adjust the EMF GDP paths as follows: Using the Cobb-Douglas production function with the DICE2007 parameters, we extract the path of exogenous technical change implied by the EMF GDP and population paths, then we recalculate the baseline GDP path taking into account climate damages resulting from the baseline emissions path.

3. Add an additional unit of carbon emissions in year *t.* (The exact unit varies by model.)

4. Recalculate the temperature effects and damages expected in all years beyond *t* resulting from this adjusted path of emissions, as in step 2.

5. Subtract the damages computed in step 2 from those in step 4 in each year. (DICE is run in 10 year time steps, FUND in annual time steps, while the time steps in PAGE vary.)

6. Discount the resulting path of marginal damages back to the year of emissions using the agreed upon fixed discount rates.

7. Calculate the SCC as the net present value of the discounted path of damages computed in step 6, divided by the unit of carbon emissions used to shock the models in step 3.

8. Multiply by 12/44 to convert from dollars per ton of carbon to dollars per ton of CO_2 (2007 dollars) in DICE and FUND. (All calculations are done in tons of CO_2 in PAGE).

The steps above were repeated in each model for multiple future years to cover the time horizons anticipated for upcoming rulemaking analysis. To maintain consistency across the three IAMs, climate damages are calculated as lost consumption in each future year.

It is important to note that each of the three models has a different default end year. The default time horizon is 2200 for PAGE, 2595 for DICE, and 3000 for the latest version of FUND. This is an issue for the multi-model approach because differences in SCC estimates may arise simply due to the model time horizon. Many consider 2200 too short a time horizon because it could miss a significant fraction of damages under certain assumptions about the growth of marginal damages and discounting, so each model is run here through 2300. This step required a small adjustment in the PAGE model only. This step also required assumptions about GDP, population, and greenhouse gas emission trajectories after 2100, the last year for which these data are available from the EMF-22 models. (A more detailed discussion of these assumptions is included in the Appendix.)

This exercise produces 45 separate distributions of the SCC for a given year, the product of 3 models, 3 discount rates, and 5 socioeconomic scenarios. This is clearly too many separate distributions for consideration in a regulatory impact analysis.

To produce a range of plausible estimates that still reflects the uncertainty in the estimation exercise, the distributions from each of the models and scenarios are equally weighed and combined to produce three separate probability distributions for SCC in a given year, one for each assumed discount rate. These distributions are then used to define a range of point estimates for the global SCC. In this way, no integrated assessment model or socioeconomic scenario is given greater weight than another. Because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context, we present SCCs based on the average values across models and socioeconomic scenarios for each discount rate.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC across models and socio-economic and emissions scenarios at the 2.5, 3, and 5 percent discount rates. The fourth value is included to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. (The full set of distributions by model and scenario combination is included in the Appendix.) As noted above, the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range.

As previously discussed, low probability, high impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high temperature outcomes, which in turn lead to higher projections of damages. Although FUND does not include catastrophic damages (in contrast to the other two models), its probabilistic treatment of the equilibrium climate sensitivity parameter will directly affect the non-catastrophic damages that are a function of the rate of temperature change.

In Table 3, we begin by presenting SCC estimates for 2010 by model, scenario, and discount rate to illustrate the variability in the SCC across each of these input parameters. As expected, higher discount rates consistently result in lower SCC values, while lower discount rates result in higher SCC values for each socioeconomic trajectory. It is also evident that there are differences in the SCC estimated across the three main models. For these estimates, FUND produces the lowest estimates, while PAGE generally produces the highest estimates.

Table 3: Disaggregated Social Cost of CO_2 Values by Model, Socio-Economic Trajectory, and Discount Rate for 2010 (in 2007 dollars)

	Discount rate:	**5%**	**3%**	**2.5%**	**3%**
Model	*Scenario*	Avg	Avg	Avg	95th
DICE	IMAGE	10.8	35.8	54.2	70.8
	MERGE	7.5	22.0	31.6	42.1
	Message	9.8	29.8	43.5	58.6
	MiniCAM	8.6	28.8	44.4	57.9
	550 Average	8.2	24.9	37.4	50.8
PAGE	IMAGE	8.3	39.5	65.5	142.4
	MERGE	5.2	22.3	34.6	82.4
	Message	7.2	30.3	49.2	115.6
	MiniCAM	6.4	31.8	54.7	115.4
	550 Average	5.5	25.4	42.9	104.7
FUND	IMAGE	-1.3	8.2	19.3	39.7
	MERGE	-0.3	8.0	14.8	41.3
	Message	-1.9	3.6	8.8	32.1
	MiniCAM	-0.6	10.2	22.2	42.6
	550 Average	-2.7	-0.2	3.0	19.4

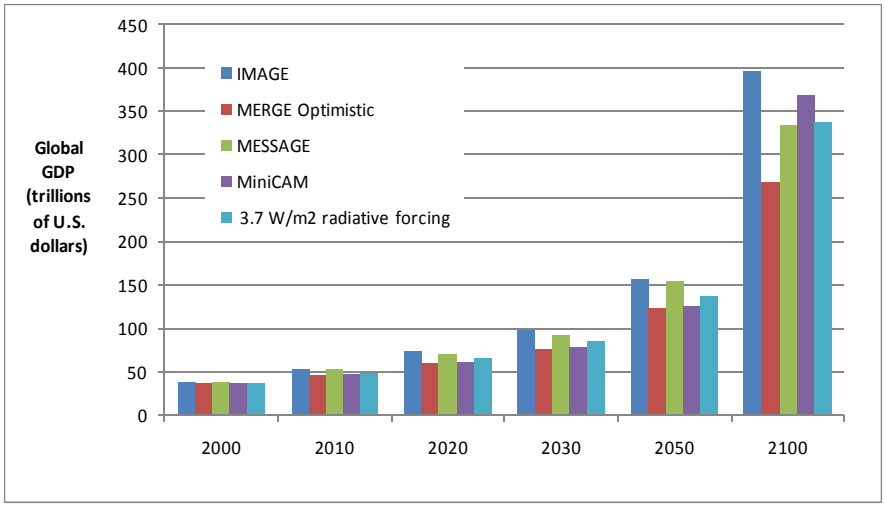
These results are not surprising when compared to the estimates in the literature for the latest versions of each model. For example, adjusting the values from the literature that were used to develop interim

SCC values to 2007 dollars for the year 2010 (assuming, as we did for the interim process, that SCC grows at 3 percent per year), FUND yields SCC estimates at or near zero for a 5 percent discount rate and around $9 per ton for a 3 percent discount rate. There are far fewer estimates using the latest versions of DICE and PAGE in the literature: Using similar adjustments to generate 2010 estimates, we calculate a SCC from DICE (based on Nordhaus 2008) of around $9 per ton for a 5 percent discount rate, and a SCC from PAGE (based on Hope 2006, 2008) close to $8 per ton for a 4 percent discount rate. Note that these comparisons are only approximate since the literature generally relies on Ramsey discounting, while we have assumed constant discount rates.[27]

The SCC estimates from FUND are sensitive to differences in emissions paths but relatively insensitive to differences in GDP paths across scenarios, while the reverse is true for DICE and PAGE. This likely occurs because of several structural differences among the models. Specifically in DICE and PAGE, the fraction of economic output lost due to climate damages increases with the level of temperature alone, whereas in FUND the fractional loss also increases with the rate of temperature change. Furthermore, in FUND increases in income over time decrease vulnerability to climate change (a form of adaptation), whereas this does not occur in DICE and PAGE. These structural differences among the models make FUND more sensitive to the path of emissions and less sensitive to GDP compared to DICE and PAGE.

Figure 3 shows that IMAGE has the highest GDP in 2100 while MERGE Optimistic has the lowest. The ordering of global GDP levels in 2100 directly corresponds to the rank ordering of SCC for PAGE and DICE. For FUND, the correspondence is less clear, a result that is to be expected given its less direct relationship between its damage function and GDP.

Figure 3: Level of Global GDP across EMF Scenarios



[27] Nordhaus (2008) runs DICE2007 with ρ = 1.5 and η = 2. The default approach in PAGE2002 (version 1.4epm) treats ρ and η as random parameters, specified using a triangular distribution such that the min, mode, and max = 0.1, 1, and 2 for ρ, and 0.5, 1, and 2 for η, respectively. The FUND default value for η is 1, and Tol generates SCC estimates for values of ρ = 0, 1, and 3 in many recent papers (e.g. Anthoff et al. 2009). The path of per-capita consumption growth, g, varies over time but is treated deterministically in two of the three models. In DICE, g is endogenous. Under Ramsey discounting, as economic growth slows in the future, the large damages from climate change that occur far out in the future are discounted at a lower rate than impacts that occur in the nearer term.

Table 4 shows the four selected SCC values in five year increments from 2010 to 2050. Values for 2010, 2020, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using a simple linear interpolation.

Table 4: Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

Discount Rate	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. Note that this approach allows us to estimate the growth rate of the SCC directly using DICE, PAGE, and FUND rather than assuming a constant annual growth rate as was done for the interim estimates (using 3 percent). This helps to ensure that the estimates are internally consistent with other modeling assumptions. Table 5 illustrates how the growth rate for these four SCC estimates varies over time. The full set of annual SCC estimates between 2010 and 2050 is reported in the Appendix.

Table 5: Changes in the Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Growth	**5%**	**3%**	**2.5%**	**3.0%**
Rate (%)	Avg	Avg	Avg	95th
2010-2020	3.6%	2.1%	1.7%	2.2%
2020-2030	3.7%	2.2%	1.8%	2.2%
2030-2040	2.7%	1.8%	1.6%	1.8%
2040-2050	2.1%	1.4%	1.1%	1.3%

While the SCC estimate grows over time, the future monetized value of emissions reductions in each year (the SCC in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. Damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency—i.e., future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate. For example,

climate damages in the year 2020 that are calculated using a SCC based on a 5 percent discount rate also should be discounted back to the analysis year using a 5 percent discount rate.[28]

V. Limitations of the Analysis

As noted, any estimate of the SCC must be taken as provisional and subject to further refinement (and possibly significant change) in accordance with evolving scientific, economic, and ethical understandings. During the course of our modeling, it became apparent that there are several areas in particular need of additional exploration and research. These caveats, and additional observations in the following section, are necessary to consider when interpreting and applying the SCC estimates.

Incomplete treatment of non-catastrophic damages. The impacts of climate change are expected to be widespread, diverse, and heterogeneous. In addition, the exact magnitude of these impacts is uncertain because of the inherent complexity of climate processes, the economic behavior of current and future populations, and our inability to accurately forecast technological change and adaptation. Current IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature (some of which are discussed above) because of lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research. Our ability to quantify and monetize impacts will undoubtedly improve with time. But it is also likely that even in future applications, a number of potentially significant damage categories will remain non-monetized. (Ocean acidification is one example of a potentially large damage from CO_2 emissions not quantified by any of the three models. Species and wildlife loss is another example that is exceedingly difficult to monetize.)

Incomplete treatment of potential catastrophic damages. There has been considerable recent discussion of the risk of catastrophic impacts and how best to account for extreme scenarios, such as the collapse of the Atlantic Meridional Overturning Circulation or the West Antarctic Ice Sheet, or large releases of methane from melting permafrost and warming oceans. Weitzman (2009) suggests that catastrophic damages are extremely large—so large, in fact, that the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. However, Nordhaus (2009) concluded that the conditions under which Weitzman's results hold "are limited and do not apply to a wide range of potential uncertain scenarios."

Using a simplified IAM, Newbold and Daigneault (2009) confirmed the potential for large catastrophe risk premiums but also showed that the aggregate benefit estimates can be highly sensitive to the shapes of both the climate sensitivity distribution and the damage function at high temperature changes. Pindyck (2009) also used a simplified IAM to examine high-impact low-probability risks, using a right-skewed gamma distribution for climate sensitivity as well as an uncertain damage coefficient, but in most cases found only a modest risk premium. Given this difference in opinion, further research in this area is needed before its practical significance can be fully understood and a reasonable approach developed to account for such risks in regulatory analysis. (The next section discusses the scientific evidence on catastrophic impacts in greater detail.)

[28] However, it is possible that other benefits or costs of proposed regulations unrelated to CO_2 emissions will be discounted at rates that differ from those used to develop the SCC estimates.

Uncertainty in extrapolation of damages to high temperatures: The damage functions in these IAMs are typically calibrated by estimating damages at moderate temperature increases (e.g., DICE was calibrated at 2.5 °C) and extrapolated to far higher temperatures by assuming that damages increase as some power of the temperature change. Hence, estimated damages are far more uncertain under more extreme climate change scenarios.

Incomplete treatment of adaptation and technological change: Each of the three integrated assessment models used here assumes a certain degree of low- or no-cost adaptation. For instance, Tol assumes a great deal of adaptation in FUND, including widespread reliance on air conditioning ; so much so, that the largest single benefit category in FUND is the reduced electricity costs from not having to run air conditioning as intensively (NRC 2009).

Climate change also will increase returns on investment to develop technologies that allow individuals to cope with adverse climate conditions, and IAMs to do not adequately account for this directed technological change.[29] For example, scientists may develop crops that are better able to withstand higher and more variable temperatures. Although DICE and FUND have both calibrated their agricultural sectors under the assumption that farmers will change land use practices in response to climate change (Mastrandrea, 2009), they do not take into account technological changes that lower the cost of this adaptation over time. On the other hand, the calibrations do not account for increases in climate variability, pests, or diseases, which could make adaptation more difficult than assumed by the IAMs for a given temperature change. Hence, models do not adequately account for potential adaptation or technical change that might alter the emissions pathway and resulting damages. In this respect, it is difficult to determine whether the incomplete treatment of adaptation and technological change in these IAMs under or overstate the likely damages.

Risk aversion: A key question unanswered during this interagency process is what to assume about relative risk aversion with regard to high-impact outcomes. These calculations do not take into account the possibility that individuals may have a higher willingness to pay to reduce the likelihood of low-probability, high-impact damages than they do to reduce the likelihood of higher-probability but lower-impact damages with the same expected cost. (The inclusion of the 95th percentile estimate in the final set of SCC values was largely motivated by this concern.) If individuals do show such a higher willingness to pay, a further question is whether that fact should be taken into account for regulatory policy. Even if individuals are not risk-averse for such scenarios, it is possible that regulatory policy should include a degree of risk-aversion.

Assuming a risk-neutral representative agent is consistent with OMB's Circular A-4, which advises that the estimates of benefits and costs used in regulatory analysis are usually based on the average or the expected value and that "emphasis on these expected values is appropriate as long as society is 'risk neutral' with respect to the regulatory alternatives. While this may not always be the case, [analysts] should in general assume 'risk neutrality' in [their] analysis."

Nordhaus (2008) points to the need to explore the relationship between risk and income in the context of climate change across models and to explore the role of uncertainty regarding various parameters in

[29] However these research dollars will be diverted from whatever their next best use would have been in the absence of climate change (so productivity/GDP would have been still higher).

the results. Using FUND, Anthoff et al (2009) explored the sensitivity of the SCC to Ramsey equation parameter assumptions based on observed behavior. They conclude that "the assumed rate of risk aversion is at least as important as the assumed rate of time preference in determining the social cost of carbon." Since Circular A-4 allows for a different assumption on risk preference in regulatory analysis if it is adequately justified, we plan to continue investigating this issue.

V. A Further Discussion of Catastrophic Impacts and Damage Functions

As noted above, the damage functions underlying the three IAMs used to estimate the SCC may not capture the economic effects of all possible adverse consequences of climate change and may therefore lead to underestimates of the SCC (Mastrandrea 2009). In particular, the models' functional forms may not adequately capture: (1) potentially discontinuous "tipping point" behavior in Earth systems, (2) inter-sectoral and inter-regional interactions, including global security impacts of high-end warming, and (3) limited near-term substitutability between damage to natural systems and increased consumption.

It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling. In the meantime, we discuss some of the available evidence.

Extrapolation of climate damages to high levels of warming

The damage functions in the models are calibrated at moderate levels of warming and should therefore be viewed cautiously when extrapolated to the high temperatures found in the upper end of the distribution. Recent science suggests that there are a number of potential climatic "tipping points" at which the Earth system may exhibit discontinuous behavior with potentially severe social and economic consequences (e.g., Lenton et al, 2008, Kriegler et al., 2009). These tipping points include the disruption of the Indian Summer Monsoon, dieback of the Amazon Rainforest and boreal forests, collapse of the Greenland Ice Sheet and the West Antarctic Ice Sheet, reorganization of the Atlantic Meridional Overturning Circulation, strengthening of El Niño-Southern Oscillation, and the release of methane from melting permafrost. Many of these tipping points are estimated to have thresholds between about 3 °C and 5 °C (Lenton et al., 2008). Probabilities of several of these tipping points were assessed through expert elicitation in 2005–2006 by Kriegler et al. (2009); results from this study are highlighted in Table 6. Ranges of probability are averaged across core experts on each topic.

As previously mentioned, FUND does not include potentially catastrophic effects. DICE assumes a small probability of catastrophic damages that increases with increased warming, but the damages from these risks are incorporated as expected values (i.e., ignoring potential risk aversion). PAGE models catastrophic impacts in a probabilistic framework (see Figure 1), so the high-end output from PAGE potentially offers the best insight into the SCC if the world were to experience catastrophic climate change. For instance, at the 95th percentile and a 3 percent discount rate, the SCC estimated by PAGE across the five socio-economic and emission trajectories of $113 per ton of CO_2 is almost double the value estimated by DICE, $58 per ton in 2010. We cannot evaluate how well the three models account for catastrophic or non-catastrophic impacts, but this estimate highlights the sensitivity of SCC values in the tails of the distribution to the assumptions made about catastrophic impacts.

Table 6: Probabilities of Various Tipping Points from Expert Elicitation -

Possible Tipping Points	Duration before effect is fully realized (in years)	Additional Warming by 2100		
		0.5-1.5 C	1.5-3.0 C	3-5 C
Reorganization of Atlantic Meridional Overturning Circulation	about 100	0-18%	6-39%	18-67%
Greenland Ice Sheet collapse	at least 300	8-39%	33-73%	67-96%
West Antarctic Ice Sheet collapse	at least 300	5-41%	10-63%	33-88%
Dieback of Amazon rainforest	about 50	2-46%	14-84%	41-94%
Strengthening of El Niño-Southern Oscillation	about 100	1-13%	6-32%	19-49%
Dieback of boreal forests	about 50	13-43%	20-81%	34-91%
Shift in Indian Summer Monsoon	about 1	Not formally assessed		
Release of methane from melting permafrost	Less than 100	Not formally assessed.		

PAGE treats the possibility of a catastrophic event probabilistically, while DICE treats it deterministically (that is, by adding the expected value of the damage from a catastrophe to the aggregate damage function). In part, this results in different probabilities being assigned to a catastrophic event across the two models. For instance, PAGE places a probability near zero on a catastrophe at 2.5 °C warming, while DICE assumes a 4 percent probability of a catastrophe at 2.5 °C. By comparison, Kriegler et al. (2009) estimate a probability of at least 16-36 percent of crossing at least one of their primary climatic tipping points in a scenario with temperatures about 2-4 °C warmer than pre-Industrial levels in 2100.

It is important to note that crossing a climatic tipping point will not necessarily lead to an economic catastrophe in the sense used in the IAMs. A tipping point is a critical threshold across which some aspect of the Earth system starts to shifts into a qualitatively different state (for instance, one with dramatically reduced ice sheet volumes and higher sea levels). In the IAMs, a catastrophe is a low-probability environmental change with high economic impact.

Failure to incorporate inter-sectoral and inter-regional interactions

The damage functions do not fully incorporate either inter-sectoral or inter-regional interactions. For instance, while damages to the agricultural sector are incorporated, the effects of changes in food supply on human health are not fully captured and depend on the modeler's choice of studies used to calibrate the IAM. Likewise, the effects of climate damages in one region of the world on another region are not included in some of the models (FUND includes the effects of migration from sea level rise). These inter-regional interactions, though difficult to quantify, are the basis for climate-induced national and economic security concerns (e.g., Campbell et al., 2007; U.S. Department of Defense 2010) and are particularly worrisome at higher levels of warming. High-end warming scenarios, for instance, project water scarcity affecting 4.3-6.9 billion people by 2050, food scarcity affecting about 120 million

additional people by 2080, and the creation of millions of climate refugees (Easterling et al., 2007; Campbell et al., 2007).

Imperfect substitutability of environmental amenities

Data from the geological record of past climate changes suggests that 6 °C of warming may have severe consequences for natural systems. For instance, during the Paleocene-Eocene Thermal Maximum about 55.5 million years ago, when the Earth experienced a geologically rapid release of carbon associated with an approximately 5 °C increase in global mean temperatures, the effects included shifts of about 400-900 miles in the range of plants (Wing et al., 2005), and dwarfing of both land mammals (Gingerich, 2006) and soil fauna (Smith et al., 2009).

The three IAMs used here assume that it is possible to compensate for the economic consequences of damages to natural systems through increased consumption of non-climate goods, a common assumption in many economic models. In the context of climate change, however, it is possible that the damages to natural systems could become so great that no increase in consumption of non-climate goods would provide complete compensation (Levy et al., 2005). For instance, as water supplies become scarcer or ecosystems become more fragile and less bio-diverse, the services they provide may become increasingly more costly to replace. Uncalibrated attempts to incorporate the imperfect substitutability of such amenities into IAMs (Sterner and Persson, 2008) indicate that the optimal degree of emissions abatement can be considerably greater than is commonly recognized.

VI. Conclusion

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are $5, $21, $35, and $65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to $24 per ton of CO_2 in 2015 and $26 per ton of CO_2 in 2020.

We noted a number of limitations to this analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes this modeling exercise even more difficult. It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling.

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Appendix

Table A1: Annual SCC Values: 2010–2050 (in 2007 dollars)

Discount Rate	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2011	4.9	21.9	35.7	66.5
2012	5.1	22.4	36.4	68.1
2013	5.3	22.8	37.0	69.6
2014	5.5	23.3	37.7	71.2
2015	5.7	23.8	38.4	72.8
2016	5.9	24.3	39.0	74.4
2017	6.1	24.8	39.7	76.0
2018	6.3	25.3	40.4	77.5
2019	6.5	25.8	41.0	79.1
2020	6.8	26.3	41.7	80.7
2021	7.1	27.0	42.5	82.6
2022	7.4	27.6	43.4	84.6
2023	7.7	28.3	44.2	86.5
2024	7.9	28.9	45.0	88.4
2025	8.2	29.6	45.9	90.4
2026	8.5	30.2	46.7	92.3
2027	8.8	30.9	47.5	94.2
2028	9.1	31.5	48.4	96.2
2029	9.4	32.1	49.2	98.1
2030	9.7	32.8	50.0	100.0
2031	10.0	33.4	50.9	102.0
2032	10.3	34.1	51.7	103.9
2033	10.6	34.7	52.5	105.8
2034	10.9	35.4	53.4	107.8
2035	11.2	36.0	54.2	109.7
2036	11.5	36.7	55.0	111.6
2037	11.8	37.3	55.9	113.6
2038	12.1	37.9	56.7	115.5
2039	12.4	38.6	57.5	117.4
2040	12.7	39.2	58.4	119.3
2041	13.0	39.8	59.0	121.0
2042	13.3	40.4	59.7	122.7
2043	13.6	40.9	60.4	124.4
2044	13.9	41.5	61.0	126.1
2045	14.2	42.1	61.7	127.8
2046	14.5	42.6	62.4	129.4
2047	14.8	43.2	63.0	131.1
2048	15.1	43.8	63.7	132.8
2049	15.4	44.4	64.4	134.5
2050	15.7	44.9	65.0	136.2

This Appendix also provides additional technical information about the non-CO_2 emission projections used in the modeling and the method for extrapolating emissions forecasts through 2300, and shows the full distribution of 2010 SCC estimates by model and scenario combination.

1. Other (non-CO_2) gases

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane (CH_4), nitrous oxide (N_2O), fluorinated gases, and net land use CO_2 emissions to 2100. These assumptions are used in all three IAMs while retaining each model's default radiative forcings (RF) due to other factors (e.g., aerosols and other gases). Specifically, to obtain the RF associated with the non-CO_2 EMF emissions only, we calculated the RF associated with the EMF atmospheric CO_2 concentrations and subtracted them from the EMF total RF.[30] This approach respects the EMF scenarios as much as possible and at the same time takes account of those components not included in the EMF projections. Since each model treats non-CO_2 gases differently (e.g., DICE lumps all other gases into one composite exogenous input), this approach was applied slightly differently in each of the models.

FUND: Rather than relying on RF for these gases, the actual emissions from each scenario were used in FUND. The model default trajectories for CH_4, N_20, SF_6, and the CO_2 emissions from land were replaced with the EMF values.

PAGE: PAGE models CO_2, CH_4, sulfur hexafluoride (SF_6), and aerosols and contains an "excess forcing" vector that includes the RF for everything else. To include the EMF values, we removed the default CH_4 and SF_6 factors[31], decomposed the excess forcing vector, and constructed a new excess forcing vector that includes the EMF RF for CH_4, N_20, and fluorinated gases, as well as the model default values for aerosols and other factors. Net land use CO_2 emissions were added to the fossil and industrial CO_2 emissions pathway.

DICE: DICE presents the greatest challenge because all forcing due to factors other than industrial CO_2 emissions is embedded in an exogenous non-CO_2 RF vector. To decompose this exogenous forcing path into EMF non-CO_2 gases and other gases, we relied on the references in DICE2007 to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) and the discussion of aerosol forecasts in the IPCC's Third Assessment Report (TAR) and in AR4, as explained below. In DICE2007, Nordhaus assumes that exogenous forcing from all non-CO_2 sources is -0.06 W/m^2 in 2005, as reported in AR4, and increases linearly to 0.3 W/m^2 in 2105, based on GISS projections, and then stays constant after that time.

[30] Note EMF did not provide CO_2 concentrations for the IMAGE reference scenario. Thus, for this scenario, we fed the fossil, industrial and land CO_2 emissions into MAGICC (considered a "neutral arbiter" model, which is tuned to emulate the major global climate models) and the resulting CO_2 concentrations were used. Note also that MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

[31] Both the model default CH_4 emissions and the initial atmospheric CH_4 is set to zero to avoid double counting the effect of past CH_4 emissions.

According to AR4, the RF in 2005 from CH_4, N_20, and halocarbons (approximately similar to the F-gases in the EMF-22 scenarios) was 0.48 + 0.16 + 0.34 = 0.98 W/m^2 and RF from total aerosols was -1.2 W/m^2. Thus, the -.06 W/m^2 non-CO_2 forcing in DICE can be decomposed into: 0.98 W/m^2 due to the EMF non-CO_2 gases, -1.2 W/m^2 due to aerosols, and the remainder, 0.16 W/m^2, due to other residual forcing.

For subsequent years, we calculated the DICE default RF from aerosols and other non-CO_2 gases based on the following two assumptions:

(1) RF from aerosols declines linearly from 2005 to 2100 at the rate projected by the TAR and then stays constant thereafter, and
(2) With respect to RF from non-CO_2 gases not included in the EMF-22 scenarios, the share of non-aerosol RF matches the share implicit in the AR4 summary statistics cited above and remains constant over time.

Assumption (1) means that the RF from aerosols in 2100 equals 66 percent of that in 2000, which is the fraction of the TAR projection of total RF from aerosols (including sulfates, black carbon, and organic carbon) in 2100 vs. 2000 under the A1B SRES emissions scenario. Since the SRES marker scenarios were not updated for the AR4, the TAR provides the most recent IPCC projection of aerosol forcing. We rely on the A1B projection from the TAR because it provides one of the lower aerosol forecasts among the SRES marker scenarios and is more consistent with the AR4 discussion of the post-SRES literature on aerosols:

Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulphur dioxide, black carbon and organic carbon, has improved in the post-SRES scenarios. Generally, these emissions are projected to be lower than reported in SRES. {WGIII 3.2, TS.3, SPM}.[32]

Assuming a simple linear decline in aerosols from 2000 to 2100 also is more consistent with the recent literature on these emissions. For example, Figure A1 shows that the sulfur dioxide emissions peak over the short-term of some SRES scenarios above the upper bound estimates of the more recent scenarios.[33] Recent scenarios project sulfur emissions to peak earlier and at lower levels compared to the SRES in part because of new information about present and planned sulfur legislation in some developing countries, such as India and China.[34] The lower bound projections of the recent literature have also shifted downward slightly compared to the SRES scenario (IPCC 2007).

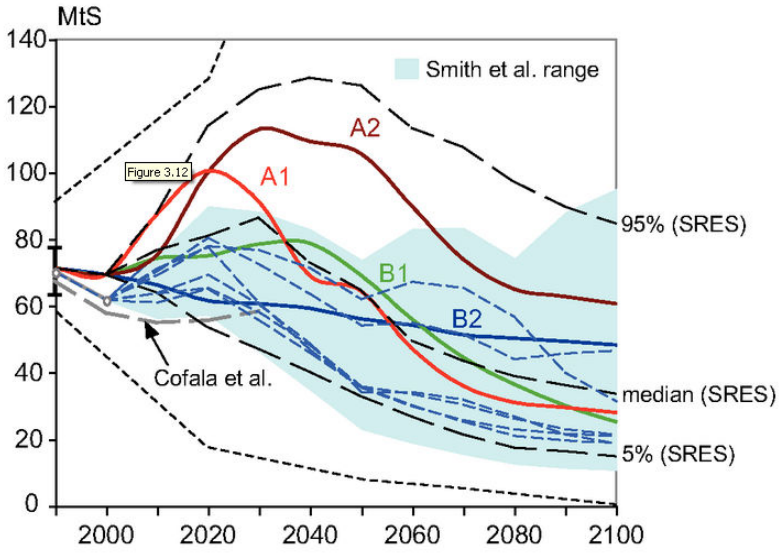
[32] AR4 Synthesis Report, p. 44, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[33] See Smith, S.J., R. Andres, E. Conception, and J. Lurz, 2004: Historical sulfur dioxide emissions, 1850-2000: methods and results. Joint Global Research Institute, College Park, 14 pp.

[34] See Carmichael, G., D. Streets, G. Calori, M. Amann, M. Jacobson, J. Hansen, and H. Ueda, 2002: Changing trends in sulphur emissions in Asia: implications for acid deposition, air pollution, and climate. Environmental Science and Technology, 36(22):4707- 4713; Streets, D., K. Jiang, X. Hu, J. Sinton, X.-Q. Zhang, D. Xu, M. Jacobson, and J. Hansen, 2001: Recent reductions in China's greenhouse gas emissions. Science, 294(5548): 1835-1837.

With these assumptions, the DICE aerosol forcing changes from -1.2 in 2005 to -0.792 in 2105 W/m^2; forcing due to other non-CO_2 gases not included in the EMF scenarios declines from 0.160 to 0.153 W/m^2.

Figure A1: Sulphur Dioxide Emission Scenarios -



Notes: Thick colored lines depict the four SRES marker scenarios and black dashed lines show the median, 5th and 95th percentile of the frequency distribution for the full ensemble of 40 SRES scenarios. The blue area (and the thin dashed lines in blue) illustrates individual scenarios and the range of Smith et al. (2004). Dotted lines indicate the minimum and maximum of SO_2 emissions scenarios developed pre-SRES.
Source: IPCC (2007), AR4 WGIII 3.2, http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch3-ens3-2-2-4.html.

Although other approaches to decomposing the DICE exogenous forcing vector are possible, initial sensitivity analysis suggests that the differences among reasonable alternative approaches are likely to be minor. For example, adjusting the TAR aerosol projection above to assume that aerosols will be maintained at 2000 levels through 2100 reduces average SCC values (for 2010) by approximately 3 percent (or less than $2); assuming all aerosols are phased out by 2100 increases average 2010 SCC values by 6-7 percent (or $0.50-$3)–depending on the discount rate. These differences increase slightly for SCC values in later years but are still well within 10 percent of each other as far out as 2050.

Finally, as in PAGE, the EMF net land use CO_2 emissions are added to the fossil and industrial CO_2 emissions pathway.

2. - Extrapolating Emissions Projections to 2300

To run each model through 2300 requires assumptions about GDP, population, greenhouse gas emissions, and radiative forcing trajectories after 2100, the last year for which these projections are available from the EMF-22 models. These inputs were extrapolated from 2100 to 2300 as follows:

1. Population growth rate declines linearly, reaching zero in the year 2200.
2. GDP/ per capita growth rate declines linearly, reaching zero in the year 2300.
3. The decline in the fossil and industrial carbon intensity (CO_2/GDP) growth rate over 2090-2100 is maintained from 2100 through 2300.
4. Net land use CO_2 emissions decline linearly, reaching zero in the year 2200.
5. Non-CO_2 radiative forcing remains constant after 2100.

Long run stabilization of GDP per capita was viewed as a more realistic simplifying assumption than a linear or exponential extrapolation of the pre-2100 economic growth rate of each EMF scenario. This is based on the idea that increasing scarcity of natural resources and the degradation of environmental sinks available for assimilating pollution from economic production activities may eventually overtake the rate of technological progress. Thus, the overall rate of economic growth may slow over the very long run. The interagency group also considered allowing an exponential decline in the growth rate of GDP per capita. However, since this would require an additional assumption about how close to zero the growth rate would get by 2300, the group opted for the simpler and more transparent linear extrapolation to zero by 2300.

The population growth rate is also assumed to decline linearly, reaching zero by 2200. This assumption is reasonably consistent with the United Nations long run population forecast, which estimates global population to be fairly stable after 2150 in the medium scenario (UN 2004).[35] The resulting range of EMF population trajectories (Figure A2) also encompass the UN medium scenario forecasts through 2300 – global population of 8.5 billion by 2200, and 9 billion by 2300.

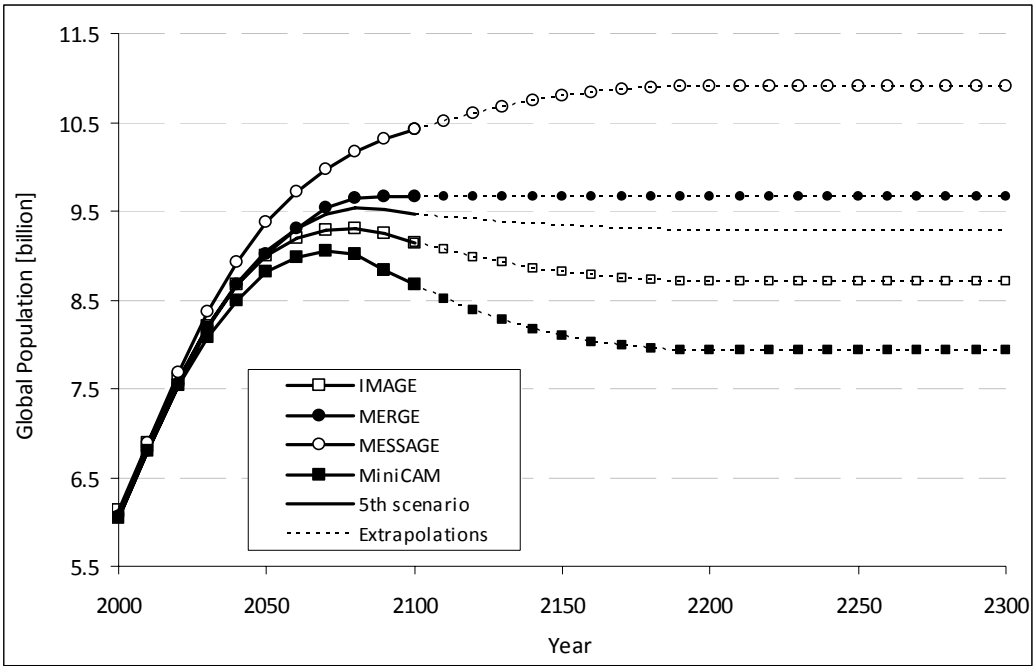
Maintaining the decline in the 2090-2100 carbon intensity growth rate (i.e., CO_2 per dollar of GDP) through 2300 assumes that technological improvements and innovations in the areas of energy efficiency and other carbon reducing technologies (possibly including currently unavailable methods) will continue to proceed at roughly the same pace that is projected to occur towards the end of the forecast period for each EMF scenario. This assumption implies that total cumulative emissions in 2300 will be between 5,000 and 12,000 GtC, which is within the range of the total potential global carbon stock estimated in the literature.

Net land use CO_2 emissions are expected to stabilize in the long run, so in the absence of any post 2100 projections, the group assumed a linear decline to zero by 2200. Given no a priori reasons for assuming a long run increase or decline in non-CO_2 radiative forcing, it is assumed to remain at the 2100 levels for each EMF scenario through 2300.

Figures A2-A7 show the paths of global population, GDP, fossil and industrial CO_2 emissions, net land CO_2 emissions, non-CO_2 radiative forcing, and CO_2 intensity (fossil and industrial CO_2 emissions/GDP) resulting from these assumptions.

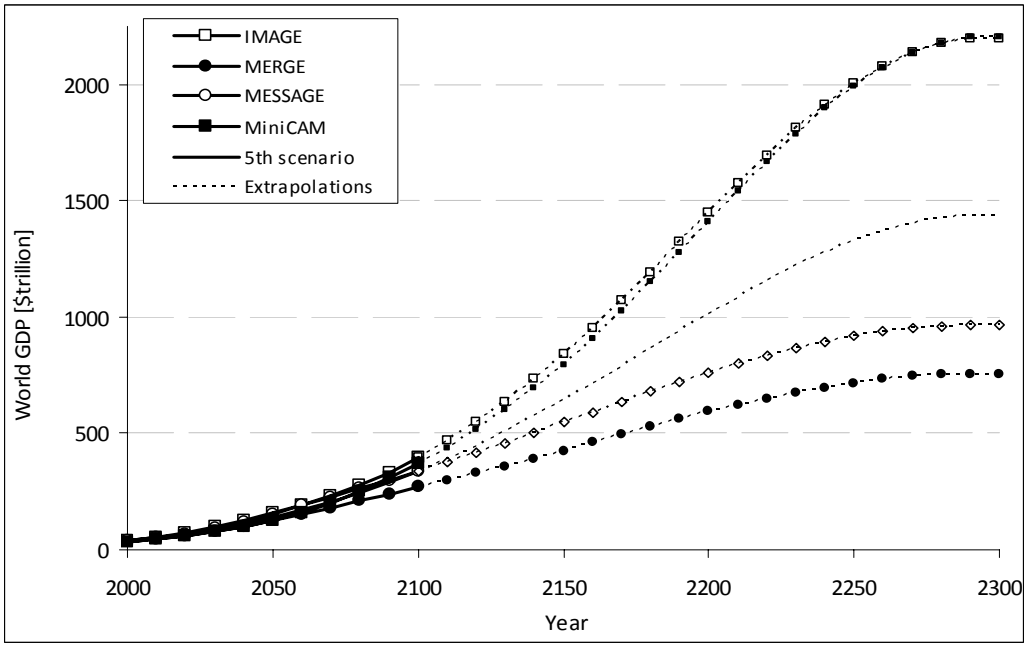
[35] United Nations. 2004. *World Population to 2300*.
http://www.un.org/esa/population/publications/longrange2/worldpop2300final.pdf

Figure A2. Global Population, 2000-2300 (Post-2100 extrapolations assume the population growth - rate changes linearly to reach a zero growth rate by 2200.) -



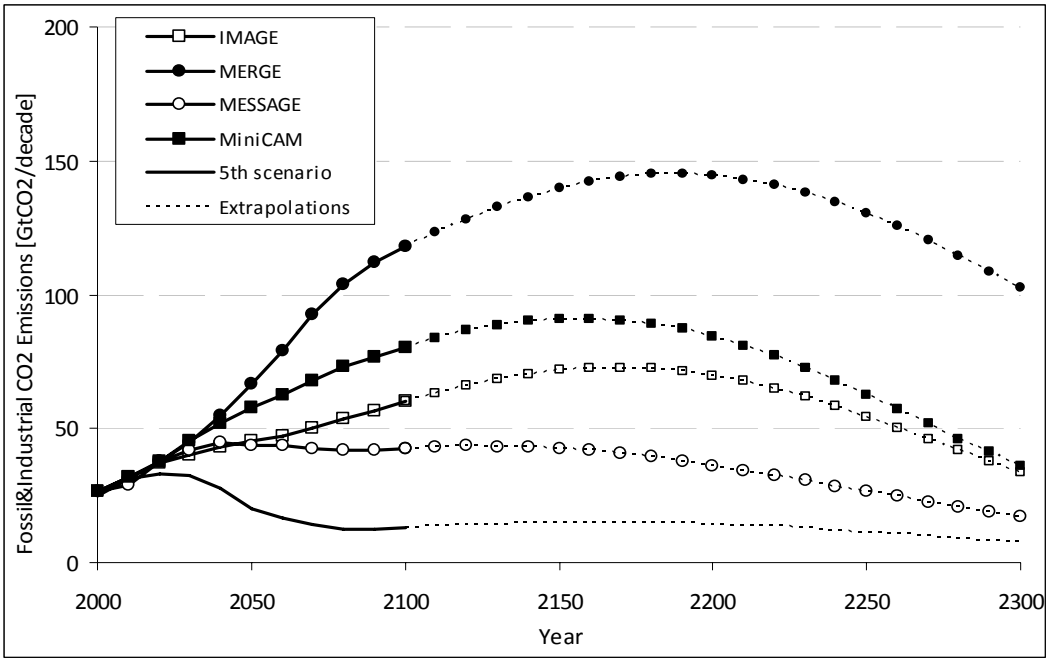
Note: In the fifth scenario, 2000-2100 population is equal to the average of the population under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Figure A3. World GDP, 2000-2300 (Post-2100 extrapolations assume GDP per capita growth declines linearly, reaching zero in the year 2300)



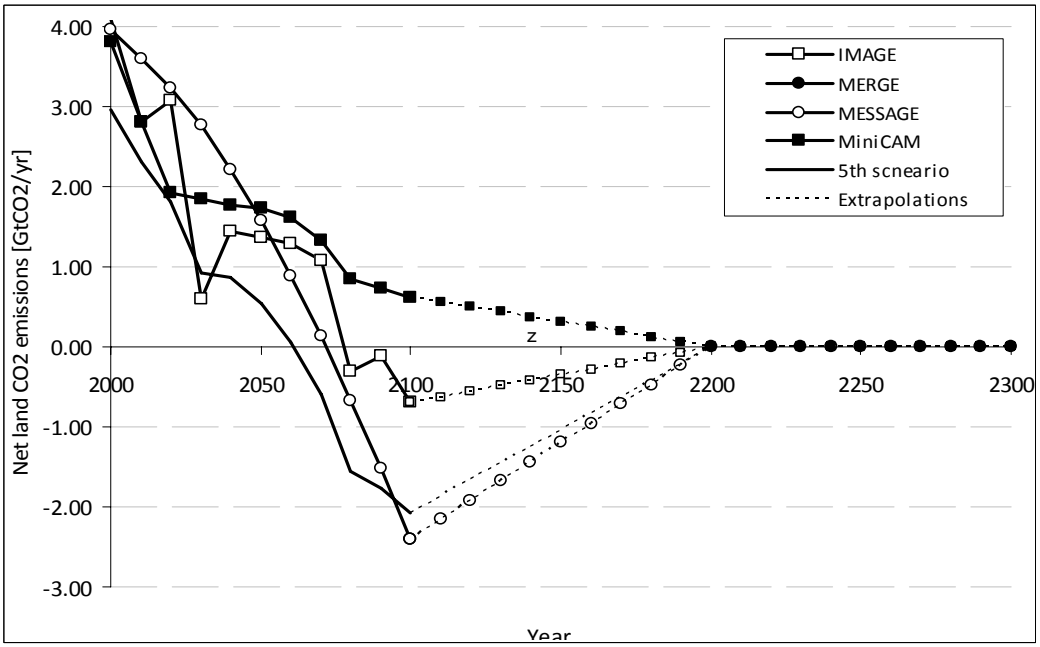
Note: In the fifth scenario, 2000-2100 GDP is equal to the average of the GDP under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Figure A4. Global Fossil and Industrial CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume growth rate of CO_2 intensity (CO_2/GDP) over 2090-2100 is maintained through 2300.)



Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO2e, full-participation, not-to-exceed scenarios considered by each of the four models.

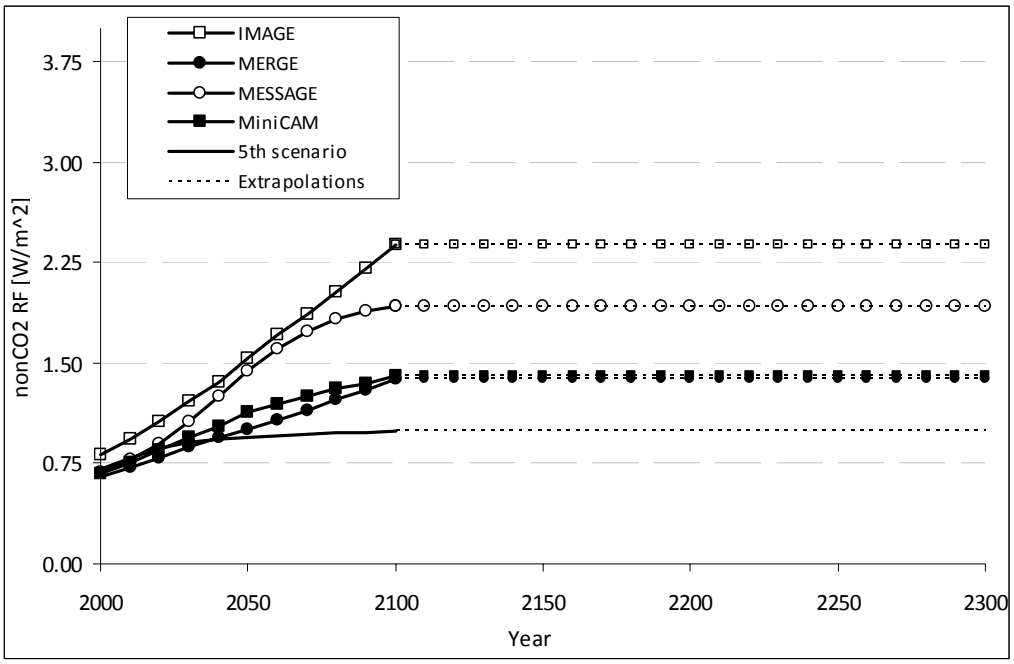
Figure A5. Global Net Land Use CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume emissions decline linearly, reaching zero in the year 2200)[36]



Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO2e, full-participation, not-to-exceed scenarios considered by each of the four models.

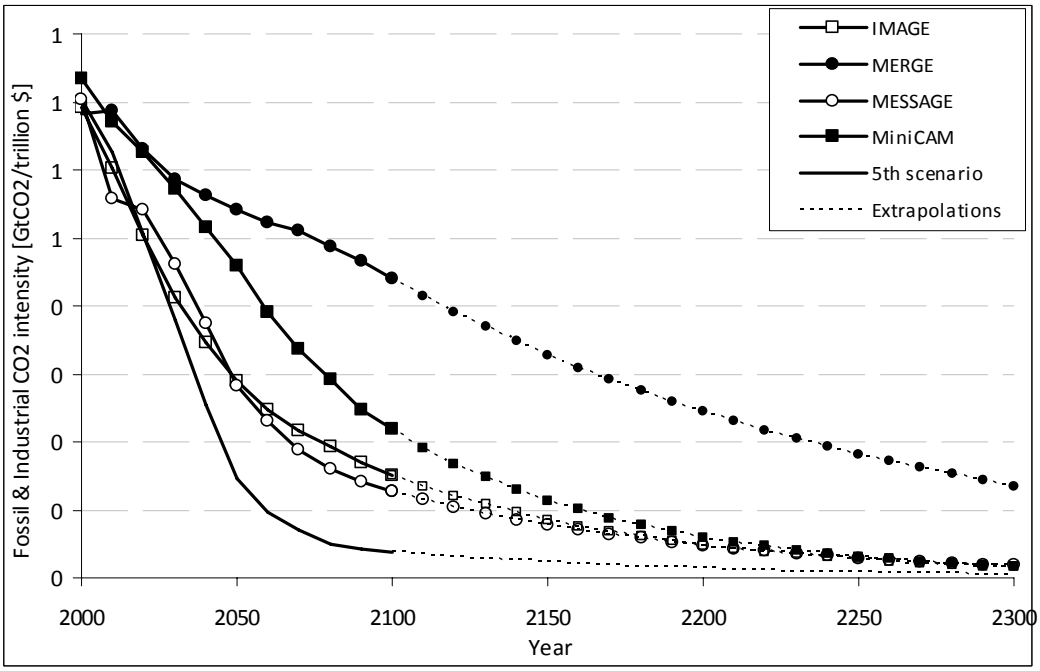
[36] MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

Figure A6. Global Non-CO_2 Radiative Forcing, 2000-2300 (Post-2100 extrapolations assume constant non-CO_2 radiative forcing after 2100.)



Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Figure A7. Global CO_2 Intensity (fossil & industrial CO_2 emissions/GDP), 2000-2300 (Post-2100 extrapolations assume decline in CO_2/GDP growth rate over 2090-2100 is maintained through 2300.)



Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Table A2. 2010 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario						**PAGE**				
IMAGE	3.3	5.9	8.1	13.9	28.8	65.5	68.2	147.9	239.6	563.8
MERGE optimistic	1.9	3.2	4.3	7.2	14.6	34.6	36.2	79.8	124.8	288.3
Message	2.4	4.3	5.8	9.8	20.3	49.2	50.7	114.9	181.7	428.4
MiniCAM base	2.7	4.6	6.4	11.2	22.8	54.7	55.7	120.5	195.3	482.3
5th scenario	2.0	3.5	4.7	8.1	16.3	42.9	41.5	103.9	176.3	371.9

Scenario						**DICE**				
IMAGE	16.4	21.4	25	33.3	46.8	54.2	69.7	96.3	111.1	130.0
MERGE optimistic	9.7	12.6	14.9	19.7	27.9	31.6	40.7	54.5	63.5	73.3
Message	13.5	17.2	20.1	27	38.5	43.5	55.1	75.8	87.9	103.0
MiniCAM base	13.1	16.7	19.8	26.7	38.6	44.4	56.8	79.5	92.8	109.3
5th scenario	10.8	14	16.7	22.2	32	37.4	47.7	67.8	80.2	96.8

Scenario						**FUND**				
IMAGE	-33.1	-18.9	-13.3	-5.5	4.1	19.3	18.7	43.5	67.1	150.7
MERGE optimistic	-33.1	-14.8	-10	-3	5.9	14.8	20.4	43.9	65.4	132.9
Message	-32.5	-19.8	-14.6	-7.2	1.5	8.8	13.8	33.7	52.3	119.2
MiniCAM base	-31.0	-15.9	-10.7	-3.4	6	22.2	21	46.4	70.4	152.9
5th scenario	-32.2	-21.6	-16.7	-9.7	-2.3	3	6.7	20.5	34.2	96.8

Table A3. 2010 Global SCC Estimates at 3 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario						**PAGE**				
IMAGE	2.0	3.5	4.8	8.1	16.5	39.5	41.6	90.3	142.4	327.4
MERGE optimistic	1.2	2.1	2.8	4.6	9.3	22.3	22.8	51.3	82.4	190.0
Message	1.6	2.7	3.6	6.2	12.5	30.3	31	71.4	115.6	263.0
MiniCAM base	1.7	2.8	3.8	6.5	13.2	31.8	32.4	72.6	115.4	287.0
5th scenario	1.3	2.3	3.1	5	9.6	25.4	23.6	62.1	104.7	222.5

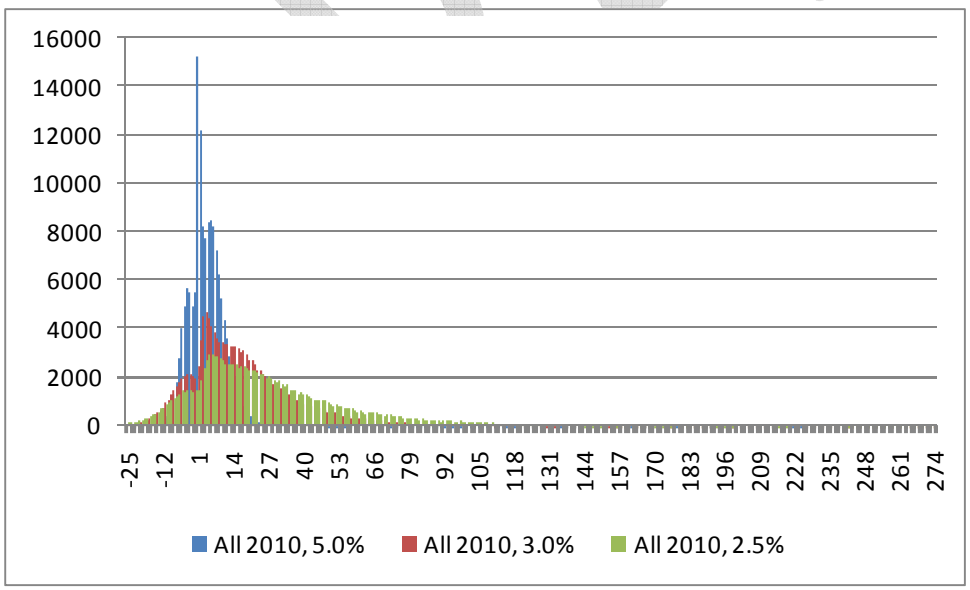
Scenario						**DICE**				
IMAGE	11.0	14.5	17.2	22.8	31.6	35.8	45.4	61.9	70.8	82.1
MERGE optimistic	7.1	9.2	10.8	14.3	19.9	22	27.9	36.9	42.1	48.8
Message	9.7	12.5	14.7	19	26.6	29.8	37.8	51.1	58.6	67.4
MiniCAM base	8.8	11.5	13.6	18	25.2	28.8	36.9	50.4	57.9	67.8
5th scenario	7.9	10.1	11.8	15.6	21.6	24.9	31.8	43.7	50.8	60.6

Scenario						**FUND**				
IMAGE	-25.2	-15.3	-11.2	-5.6	0.9	8.2	10.4	25.4	39.7	90.3
MERGE optimistic	-24.0	-12.4	-8.7	-3.6	2.6	8	12.2	27	41.3	85.3
Message	-25.3	-16.2	-12.2	-6.8	-0.5	3.6	7.7	20.1	32.1	72.5
MiniCAM base	-23.1	-12.9	-9.3	-4	2.4	10.2	12.2	27.7	42.6	93.0
5th scenario	-24.1	-16.6	-13.2	-8.3	-3	-0.2	2.9	11.2	19.4	53.6

Table A4. 2010 Global SCC Estimates at 5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	0.5	0.8	1.1	1.8	3.5	8.3	8.5	19.5	31.4	67.2
MERGE optimistic	0.3	0.5	0.7	1.2	2.3	5.2	5.4	12.3	19.5	42.4
Message	0.4	0.7	0.9	1.6	3	7.2	7.2	17	28.2	60.8
MiniCAM base	0.3	0.6	0.8	1.4	2.7	6.4	6.6	15.9	24.9	52.6
5th scenario	0.3	0.6	0.8	1.3	2.3	5.5	5	12.9	22	48.7
Scenario	**DICE**									
IMAGE	4.2	5.4	6.2	7.6	10	10.8	13.4	16.8	18.7	21.1
MERGE optimistic	2.9	3.7	4.2	5.3	7	7.5	9.3	11.7	12.9	14.4
Message	3.9	4.9	5.5	7	9.2	9.8	12.2	15.4	17.1	18.8
MiniCAM base	3.4	4.2	4.7	6	7.9	8.6	10.7	13.5	15.1	16.9
5th scenario	3.2	4	4.6	5.7	7.6	8.2	10.2	12.8	14.3	16.0
Scenario	**FUND**									
IMAGE	-11.7	-8.4	-6.9	-4.6	-2.2	-1.3	0.7	4.1	7.4	17.4
MERGE optimistic	-10.6	-7.1	-5.6	-3.6	-1.3	-0.3	1.6	5.4	9.1	19.0
Message	-12.2	-8.9	-7.3	-4.9	-2.5	-1.9	0.3	3.5	6.5	15.6
MiniCAM base	-10.4	-7.2	-5.8	-3.8	-1.5	-0.6	1.3	4.8	8.2	18.0
5th scenario	-10.9	-8.3	-7	-5	-2.9	-2.7	-0.8	1.4	3.2	9.2

Figure A8. Histogram of Global SCC Estimates in 2010 (2007$/ton CO_2), by discount rate



* The distribution of SCC values ranges from -$5,192 to $66,116 but the X-axis has been truncated at approximately the 1st and 99th percentiles to better show the data.

Table A5. Additional Summary Statistics of 2010 Global SCC Estimates -

Discount rate:	5%				3%				2.5%			
Scenario	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis
DICE	9.0	13.1	0.8	0.2	28.3	209.8	1.1	0.9	42.2	534.9	1.2	1.1
PAGE	6.5	136.0	6.3	72.4	29.8	3,383.7	8.6	151.0	49.3	9,546.0	8.7	143.8
FUND	-1.3	70.1	28.2	1,479.0	6.0	16,382.5	128.0	18,976.5	13.6	150,732.6	149.0	23,558.3

DRAFT

Technical Support Document: -
Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis -
Under Executive Order 12866 -

Interagency Working Group on Social Cost of Carbon, United States Government

With participation by

Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of Transportation
Environmental Protection Agency
National Economic Council
Office of Management and Budget
Office of Science and Technology Policy
Department of the Treasury

May 2013

Executive Summary

Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the "social cost of carbon" (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that impact cumulative global emissions. The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

The interagency process that developed the original U.S. government's SCC estimates is described in the 2010 interagency technical support document (TSD) (Interagency Working Group on Social Cost of Carbon 2010). Through that process the interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models (IAMs), at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

While acknowledging the continued limitations of the approach taken by the interagency group in 2010, this document provides an update of the SCC estimates based on new versions of each IAM (DICE, PAGE, and FUND). It does not revisit other interagency modeling decisions (e.g., with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity). Improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature.

The SCC estimates using the updated versions of the models are higher than those reported in the 2010 TSD. By way of comparison, the four 2020 SCC estimates reported in the 2010 TSD were $7, $26, $42 and $81 (2007$). The corresponding four updated SCC estimates for 2020 are $12, $43, $65, and $129 (2007$). The model updates that are relevant to the SCC estimates include: an explicit representation of sea level rise damages in the DICE and PAGE models; updated adaptation assumptions, revisions to ensure damages are constrained by GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages in the PAGE model; an updated carbon cycle in the DICE model; and updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the transient response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions in the FUND model. The SCC estimates vary by year, and the following table summarizes the revised SCC estimates from 2010 through 2050.

Revised Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per metric ton of CO_2)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	11	33	52	90
2015	12	38	58	109
2020	12	43	65	129
2025	14	48	70	144
2030	16	52	76	159
2035	19	57	81	176
2040	21	62	87	192
2045	24	66	92	206
2050	27	71	98	221

I. Purpose

The purpose of this document is to update the schedule of social cost of carbon (SCC) estimates from the 2010 interagency technical support document (TSD) (Interagency Working Group on Social Cost of Carbon 2010).[1] E.O. 13563 commits the Administration to regulatory decision making "based on the best available science."[2] Additionally, the interagency group recommended in 2010 that the SCC estimates be revisited on a regular basis or as model updates that reflect the growing body of scientific and economic knowledge become available.[3] New versions of the three integrated assessment models used by the U.S. government to estimate the SCC (DICE, FUND, and PAGE), are now available and have been published in the peer reviewed literature. While acknowledging the continued limitations of the approach taken by the interagency group in 2010 (documented in the original 2010 TSD), this document provides an update of the SCC estimates based on the latest peer-reviewed version of the models, replacing model versions that were developed up to ten years ago in a rapidly evolving field. It does not revisit other assumptions with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity. Improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature. The agencies participating in the interagency working group continue to investigate potential improvements to the way in which economic damages associated with changes in CO_2 emissions are quantified.

Section II summarizes the major updates relevant to SCC estimation that are contained in the new versions of the integrated assessment models released since the 2010 interagency report. Section III presents the updated schedule of SCC estimates for 2010 – 2050 based on these versions of the models. Section IV provides a discussion of other model limitations and research gaps.

II. Summary of Model Updates

This section briefly summarizes changes to the most recent versions of the three integrated assessment models (IAMs) used by the interagency group in 2010. We focus on describing those model updates that are relevant to estimating the social cost of carbon, as summarized in Table 1. For example, both the DICE and PAGE models now include an explicit representation of sea level rise damages. Other revisions to PAGE include: updated adaptation assumptions, revisions to ensure damages are constrained by GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages. The DICE model's simple carbon cycle has been updated to be more consistent with a more complex climate model. The FUND model includes updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the transient response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of

[1] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).

[2] http://www.whitehouse.gov/sites/default/files/omb/inforeg/eo12866/eo13563_01182011.pdf

[3] See p. 1, 3, 4, 29, and 33 (Interagency Working Group on Social Cost of Carbon 2010).

methane emissions. Changes made to parts of the models that are superseded by the interagency working group's modeling assumptions – regarding equilibrium climate sensitivity, discounting, and socioeconomic variables – are not discussed here but can be found in the references provided in each section below.

Table 1: Summary of Key Model Revisions Relevant to the Interagency SCC

IAM	Version used in 2010 Interagency Analysis	New Version	Key changes relevant to interagency SCC
DICE	2007	2010	Updated calibration of the carbon cycle model and explicit representation of sea level rise (SLR) and associated damages.
FUND	3.5 (2009)	3.8 (2012)	Updated damage functions for space heating, SLR, agricultural impacts, changes to transient response of temperature to buildup of GHG concentrations, and inclusion of indirect climate effects of methane.
PAGE	2002	2009	Explicit representation of SLR damages, revisions to damage function to ensure damages do not exceed 100% of GDP, change in regional scaling of damages, revised treatment of potential abrupt damages, and updated adaptation assumptions.

A. DICE

DICE 2010 includes a number of changes over the previous 2007 version used in the 2010 interagency report. The model changes that are relevant for the SCC estimates developed by the interagency working group include: 1) updated parameter values for the carbon cycle model, 2) an explicit representation of sea level dynamics, and 3) a re-calibrated damage function that includes an explicit representation of economic damages from sea level rise. Changes were also made to other parts of the DICE model—including the equilibrium climate sensitivity parameter, the rate of change of total factor productivity, and the elasticity of the marginal utility of consumption—but these components of DICE are superseded by the interagency working group's assumptions and so will not be discussed here. More details on DICE2007 can be found in Nordhaus (2008) and on DICE2010 in Nordhaus (2010). The DICE2010 model and documentation is also available for download from the homepage of William Nordhaus.

Carbon Cycle Parameters

DICE uses a three-box model of carbon stocks and flows to represent the accumulation and transfer of carbon among the atmosphere, the shallow ocean and terrestrial biosphere, and the deep ocean. These parameters are "calibrated to match the carbon cycle in the Model for the Assessment of Greenhouse

Gas Induced Climate Change (MAGICC)" (Nordhaus 2008 p 44).[4] Carbon cycle transfer coefficient values in DICE2010 are based on re-calibration of the model to match the newer 2009 version of MAGICC (Nordhaus 2010 p 2). For example, in DICE2010, in each decade, 12 percent of the carbon in the atmosphere is transferred to the shallow ocean, 4.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 94.8 percent remains in the shallow ocean, and 0.5 percent is transferred to the deep ocean. For comparison, in DICE 2007, 18.9 percent of the carbon in the atmosphere is transferred to the shallow ocean each decade, 9.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 85.3 percent remains in the shallow ocean, and 5 percent is transferred to the deep ocean.

The implication of these changes for DICE2010 is in general a weakening of the ocean as a carbon sink and therefore a higher concentration of carbon in the atmosphere than in DICE2007, for a given path of emissions. All else equal, these changes will generally increase the level of warming and therefore the SCC estimates in DICE2010 relative to those from DICE2007.

Sea Level Dynamics

A new feature of DICE2010 is an explicit representation of the dynamics of the global average sea level anomaly to be used in the updated damage function (discussed below). This section contains a brief description of the sea level rise (SLR) module; a more detailed description can be found on the model developer's website.[5] The average global sea level anomaly is modeled as the sum of four terms that represent contributions from: 1) thermal expansion of the oceans, 2) melting of glaciers and small ice caps, 3) melting of the Greenland ice sheet, and 4) melting of the Antarctic ice sheet.

The parameters of the four components of the SLR module are calibrated to match consensus results from the IPCC's Fourth Assessment Report (AR4).[6] The rise in sea level from thermal expansion in each time period (decade) is 2 percent of the difference between the sea level in the previous period and the long run equilibrium sea level, which is 0.5 meters per degree Celsius (°C) above the average global temperature in 1900. The rise in sea level from the melting of glaciers and small ice caps occurs at a rate of 0.008 meters per decade per °C above the average global temperature in 1900.

The contribution to sea level rise from melting of the Greenland ice sheet is more complex. The equilibrium contribution to SLR is 0 meters for temperature anomalies less than 1 ^{o}C and increases linearly from 0 meters to a maximum of 7.3 meters for temperature anomalies between 1 ^{o}C and 3.5 °C. The contribution to SLR in each period is proportional to the difference between the previous period's sea level anomaly and the equilibrium sea level anomaly, where the constant of proportionality increases with the temperature anomaly in the current period.

[4] MAGICC is a simple climate model initially developed by the U.S. National Center for Atmospheric Research that has been used heavily by the Intergovernmental Panel on Climate Change (IPCC) to emulate projections from more sophisticated state of the art earth system simulation models (Randall et al. 2007).

[5] Documentation on the new sea level rise module of DICE is available on William Nordhaus' website at: http://nordhaus.econ.yale.edu/documents/SLR_021910.pdf.

[6] For a review of post-IPCC AR4 research on sea level rise, see Nicholls et al. (2011) and NAS (2011).

The contribution to SLR from the melting of the Antarctic ice sheet is -0.001 meters per decade when the temperature anomaly is below 3 °C and increases linearly between 3 °C and 6 °C to a maximum rate of 0.025 meters per decade at a temperature anomaly of 6 °C.

Re-calibrated Damage Function

Economic damages from climate change in the DICE model are represented by a fractional loss of gross economic output in each period. A portion of the remaining economic output in each period (net of climate change damages) is consumed and the remainder is invested in the physical capital stock to support future economic production, so each period's climate damages will reduce consumption in that period and in all future periods due to the lost investment. The fraction of output in each period that is lost due to climate change impacts is represented as one minus a fraction, which is one divided by a quadratic function of the temperature anomaly, producing a sigmoid ("S"-shaped) function.[7] The loss function in DICE2010 has been expanded by adding a quadratic function of SLR to the quadratic function of temperature. In DICE2010 the temperature anomaly coefficients have been recalibrated to avoid double-counting damages from sea level rise that were implicitly included in these parameters in DICE2007.

The aggregate damages in DICE2010 are illustrated by Nordhaus (2010 p 3), who notes that "…damages in the uncontrolled (baseline) [i.e., reference] case … in 2095 are $12 trillion, or 2.8 percent of global output, for a global temperature increase of 3.4 °C above 1900 levels." This compares to a loss of 3.2 percent of global output at 3.4 °C in DICE2007. However, in DICE2010, annual damages are lower in most of the early periods of the modeling horizon but higher in later periods than would be calculated using the DICE2007 damage function. Specifically, the percent difference between damages in the base run of DICE2010 and those that would be calculated using the DICE2007 damage function starts at +7 percent in 2005, decreases to a low of -14 percent in 2065, then continuously increases to +20 percent by 2300 (the end of the interagency analysis time horizon), and to +160 percent by the end of the model time horizon in 2595. The large increases in the far future years of the time horizon are due to the permanence associated with damages from sea level rise, along with the assumption that the sea level is projected to continue to rise long after the global average temperature begins to decrease. The changes to the loss function generally decrease the interagency working group SCC estimates slightly given that relative increases in damages in later periods are discounted more heavily, all else equal.

B. FUND

FUND version 3.8 includes a number of changes over the previous version 3.5 (Narita et al. 2010) used in the 2010 interagency report. Documentation supporting FUND and the model's source code for all versions of the model is available from the model authors.[8] Notable changes, due to their impact on the

[7] The model and documentation, including formulas, are available on the author's webpage at http://www.econ.yale.edu/~nordhaus/homepage/RICEmodels.htm.

[8] http://www.fund-model.org/. This report uses version 3.8 of the FUND model, which represents a modest update to the most recent version of the model to appear in the literature (version 3.7) (Anthoff and Tol, 2013). For the purpose of computing the SCC, the relevant changes (between 3.7 to 3.8) are associated with improving

SCC estimates, are adjustments to the space heating, agriculture, and sea level rise damage functions in addition to changes to the temperature response function and the inclusion of indirect effects from methane emissions.[9] We discuss each of these in turn.

Space Heating

In FUND, the damages associated with the change in energy needs for space heating are based on the estimated impact due to one degree of warming. These baseline damages are scaled based on the forecasted temperature anomaly's deviation from the one degree benchmark and adjusted for changes in vulnerability due to economic and energy efficiency growth. In FUND 3.5, the function that scales the base year damages adjusted for vulnerability allows for the possibility that in some simulations the benefits associated with reduced heating needs may be an unbounded convex function of the temperature anomaly. In FUND 3.8, the form of the scaling has been modified to ensure that the function is everywhere concave and that there will exist an upper bound on the benefits a region may receive from reduced space heating needs. The new formulation approaches a value of two in the limit of large temperature anomalies, or in other words, assuming no decrease in vulnerability, the reduced expenditures on space heating at any level of warming will not exceed two times the reductions experienced at one degree of warming. Since the reduced need for space heating represents a benefit of climate change in the model, or a negative damage, this change will increase the estimated SCC. This update accounts for a significant portion of the difference in the expected SCC estimates reported by the two versions of the model when run probabilistically.

Sea Level Rise and Land Loss

The FUND model explicitly includes damages associated with the inundation of dry land due to sea level rise. The amount of land lost within a region is dependent upon the proportion of the coastline being protected by adequate sea walls and the amount of sea level rise. In FUND 3.5 the function defining the potential land lost in a given year due to sea level rise is linear in the rate of sea level rise for that year. This assumption implicitly assumes that all regions are well represented by a homogeneous coastline in length and a constant uniform slope moving inland. In FUND 3.8 the function defining the potential land lost has been changed to be a convex function of sea level rise, thereby assuming that the slope of the shore line increases moving inland. The effect of this change is to typically reduce the vulnerability of some regions to sea level rise based land loss, thereby lowering the expected SCC estimate. [10]

Agriculture

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consistency with IPCC AR4 by adjusting the atmospheric lifetimes of CH4 and N2O and incorporating the indirect forcing effects of CH4, along with making minor stability improvements in the sea wall construction algorithm.

[9] The other damage sectors (water resources, space cooling, land loss, migration, ecosystems, human health, and extreme weather) were not significantly updated.

[10] For stability purposes this report also uses an update to the model which assumes that regional coastal protection measures will be built to protect the most valuable land first, such that the marginal benefits of coastal protection is decreasing in the level of protection following Fankhauser (1995).

In FUND, the damages associated with the agricultural sector are measured as proportional to the sector's value. The fraction is bounded from above by one and is made up of three additive components that represent the effects from carbon fertilization, the rate of temperature change, and the level of the temperature anomaly. In both FUND 3.5 and FUND 3.8, the fraction of the sector's value lost due to the level of the temperature anomaly is modeled as a quadratic function with an intercept of zero. In FUND 3.5, the coefficients of this loss function are modeled as the ratio of two random normal variables. This specification had the potential for unintended extreme behavior as draws from the parameter in the denominator approached zero or went negative. In FUND 3.8, the coefficients are drawn directly from truncated normal distributions so that they remain in the range $[0,\infty)$ and $(-\infty,0]$, respectively, ensuring the correct sign and eliminating the potential for divide by zero errors. The means for the new distributions are set equal to the ratio of the means from the normal distributions used in the previous version. In general the impact of this change has been to decrease the range of the distribution while spreading out the distributions' mass over the remaining range relative to the previous version. The net effect of this change on the SCC estimates is difficult to predict.

Transient Temperature Response

The temperature response model translates changes in global levels of radiative forcing into the current expected temperature anomaly. In FUND, a given year's increase in the temperature anomaly is based on a mean reverting function where the mean equals the equilibrium temperature anomaly that would eventually be reached if that year's level of radiative forcing were sustained. The rate of mean reversion defines the rate at which the transient temperature approaches the equilibrium. In FUND 3.5, the rate of temperature response is defined as a decreasing linear function of equilibrium climate sensitivity to capture the fact that the progressive heat uptake of the deep ocean causes the rate to slow at higher values of the equilibrium climate sensitivity. In FUND 3.8, the rate of temperature response has been updated to a quadratic function of the equilibrium climate sensitivity. This change reduces the sensitivity of the rate of temperature response to the level of the equilibrium climate sensitivity, a relationship first noted by Hansen et al. (1985) based on the heat uptake of the deep ocean. Therefore in FUND 3.8, the temperature response will typically be faster than in the previous version. The overall effect of this change is likely to increase estimates of the SCC as higher temperatures are reached during the timeframe analyzed and as the same damages experienced in the previous version of the model are now experienced earlier and therefore discounted less.

Methane

The IPCC AR4 notes a series of indirect effects of methane emissions, and has developed methods for proxying such effects when computing the global warming potential of methane (Forster et al. 2007). FUND 3.8 now includes the same methods for incorporating the indirect effects of methane emissions. Specifically, the average atmospheric lifetime of methane has been set to 12 years to account for the feedback of methane emissions on its own lifetime. The radiative forcing associated with atmospheric methane has also been increased by 40% to account for its net impact on ozone production and stratospheric water vapor. All else equal, the effect of this increased radiative forcing will be to increase the estimated SCC values, due to greater projected temperature anomaly.

C. PAGE

PAGE09 (Hope 2013) includes a number of changes from PAGE2002, the version used in the 2010 SCC interagency report. The changes that most directly affect the SCC estimates include: explicitly modeling the impacts from sea level rise, revisions to the damage function to ensure damages are constrained by GDP, a change in the regional scaling of damages, a revised treatment for the probability of a discontinuity within the damage function, and revised assumptions on adaptation. The model also includes revisions to the carbon cycle feedback and the calculation of regional temperatures.[11] More details on PAGE09 can be found in Hope (2011a, 2011b, 2011c). A description of PAGE2002 can be found in Hope (2006).

Sea Level Rise

While PAGE2002 aggregates all damages into two categories – economic and non-economic impacts -, PAGE09 adds a third explicit category: damages from sea level rise. In the previous version of the model, damages from sea level rise were subsumed by the other damage categories. In PAGE09 sea level damages increase less than linearly with sea level under the assumption that land, people, and GDP are more concentrated in low-lying shoreline areas. Damages from the economic and non-economic sector were adjusted to account for the introduction of this new category.

Revised Damage Function to Account for Saturation

In PAGE09, small initial economic and non-economic benefits (negative damages) are modeled for small temperature increases, but all regions eventually experience economic damages from climate change, where damages are the sum of additively separable polynomial functions of temperature and sea level rise. Damages transition from this polynomial function to a logistic path once they exceed a certain proportion of remaining Gross Domestic Product (GDP) to ensure that damages do not exceed 100 percent of GDP. This differs from PAGE2002, which allowed Eastern Europe to potentially experience large benefits from temperature increases, and which also did not bound the possible damages that could be experienced.

Regional Scaling Factors

As in the previous version of PAGE, the PAGE09 model calculates the damages for the European Union (EU) and then, assumes that damages for other regions are proportional based on a given scaling factor. The scaling factor in PAGE09 is based on the length of a region's coastline relative to the EU (Hope 2011b). Because of the long coastline in the EU, other regions are, on average, less vulnerable than the EU for the same sea level and temperature increase, but all regions have a positive scaling factor. PAGE2002 based its scaling factors on four studies reported in the IPCC's third assessment report, and allowed for benefits from temperature increase in Eastern Europe, smaller impacts in developed countries, and higher damages in developing countries.

[11] Because several changes in the PAGE model are structural (e.g., the addition of sea level rise and treatment of discontinuity), it is not possible to assess the direct impact of each change on the SCC in isolation as done for the other two models above.

Probability of a Discontinuity

In PAGE2002, the damages associated with a "discontinuity" (nonlinear extreme event) were modeled as an expected value. Specifically, a stochastic probability of a discontinuity was multiplied by the damages associated with a discontinuity to obtain an expected value, and this was added to the economic and non-economic impacts. That is, additional damages from an extreme event, such as extreme melting of the Greenland ice sheet, were multiplied by the probability of the event occurring and added to the damage estimate. In PAGE09, the probability of discontinuity is treated as a discrete event for each year in the model. The damages for each model run are estimated either with or without a discontinuity occurring, rather than as an expected value. A large-scale discontinuity becomes possible when the temperature rises beyond some threshold value between 2 and 4°C. The probability that a discontinuity will occur beyond this threshold then increases by between 10 and 30 percent for every 1°C rise in temperature beyond the threshold. If a discontinuity occurs, the EU loses an additional 5 to 25 percent of its GDP (drawn from a triangular distribution with a mean of 15 percent) in addition to other damages, and other regions lose an amount determined by the regional scaling factor. The threshold value for a possible discontinuity is lower than in PAGE2002, while the rate at which the probability of a discontinuity increases with the temperature anomaly and the damages that result from a discontinuity are both higher than in PAGE2002. The model assumes that only one discontinuity can occur and that the impact is phased in over a period of time, but once it occurs, its effect is permanent.

Adaptation

As in PAGE2002, adaptation is available to help mitigate any climate change impacts that occur. In PAGE this adaptation is the same regardless of the temperature change or sea level rise and is therefore akin to what is more commonly considered a reduction in vulnerability. It is modeled by reducing the damages by some percentage. PAGE09 assumes a smaller decrease in vulnerability than the previous version of the model and assumes that it will take longer for this change in vulnerability to be realized. In the aggregated economic sector, at the time of full implementation, this adaptation will mitigate all damages up to a temperature increase of 1°C, and for temperature anomalies between 1°C and 2°C, it will reduce damages by 15-30 percent (depending on the region). However, it takes 20 years to fully implement this adaptation. In PAGE2002, adaptation was assumed to reduce economic sector damages up to 2°C by 50-90 percent after 20 years. Beyond 2°C, no adaptation is assumed to be available to mitigate the impacts of climate change. For the non-economic sector, in PAGE09 adaptation is available to reduce 15 percent of the damages due to a temperature increase between 0°C and 2°C and is assumed to take 40 years to fully implement, instead of 25 percent of the damages over 20 years assumed in PAGE2002. Similarly, adaptation is assumed to alleviate 25-50 percent of the damages from the first 0.20 to 0.25 meters of sea level rise but is assumed to be ineffective thereafter. Hope (2011c) estimates that the less optimistic assumptions regarding the ability to offset impacts of temperature and sea level rise via adaptation increase the SCC by approximately 30 percent.

Other Noteworthy Changes

Two other changes in the model are worth noting. There is a change in the way the model accounts for decreased CO_2 absorption on land and in the ocean as temperature rises. PAGE09 introduces a linear feedback from global mean temperature to the percentage gain in the excess concentration of CO_2, capped at a maximum level. In PAGE2002, an additional amount was added to the CO_2 emissions each period to account for a decrease in ocean absorption and a loss of soil carbon. Also updated is the method by which the average global and annual temperature anomaly is downscaled to determine annual average regional temperature anomalies to be used in the regional damage functions. In PAGE2002, the scaling was determined solely based on regional difference in emissions of sulfate aerosols. In PAGE09, this regional temperature anomaly is further adjusted using an additive factor that is based on the average absolute latitude of a region relative to the area weighted average absolute latitude of the Earth's landmass, to capture relatively greater changes in temperature forecast to be experienced at higher latitudes.

III. Revised SCC Estimates

The updated versions of the three integrated assessment models were run using the same methodology detailed in the 2010 TSD (Interagency Working Group on Social Cost of Carbon 2010). The approach along with the inputs for the socioeconomic emissions scenarios, equilibrium climate sensitivity distribution, and discount rate remains the same. This includes the five reference scenarios based on the EMF-22 modeling exercise, the Roe and Baker equilibrium climate sensitivity distribution calibrated to the IPCC AR4, and three constant discount rates of 2.5, 3, and 5 percent.

As was previously the case, the use of three models, three discount rates, and five scenarios produces 45 separate distributions for the global SCC. The approach laid out in the 2010 TSD applied equal weight to each model and socioeconomic scenario in order to reduce the dimensionality down to three separate distributions representative of the three discount rates. The interagency group selected four values from these distributions for use in regulatory analysis. Three values are based on the average SCC across models and socio-economic-emissions scenarios at the 2.5, 3, and 5 percent discount rates, respectively. The fourth value was chosen to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, the 95th percentile of the SCC estimates at a 3 percent discount rate was chosen. (A detailed set of percentiles by model and scenario combination and additional summary statistics for the 2020 values is available in the Appendix.) As noted in the 2010 TSD, "the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate" (Interagency Working Group on Social Cost of Carbon 2010, p. 25). However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the interagency group emphasizes the importance and value of including all four SCC values.

Table 2 shows the four selected SCC estimates in five year increments from 2010 to 2050. Values for 2010, 2020, 2030, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per

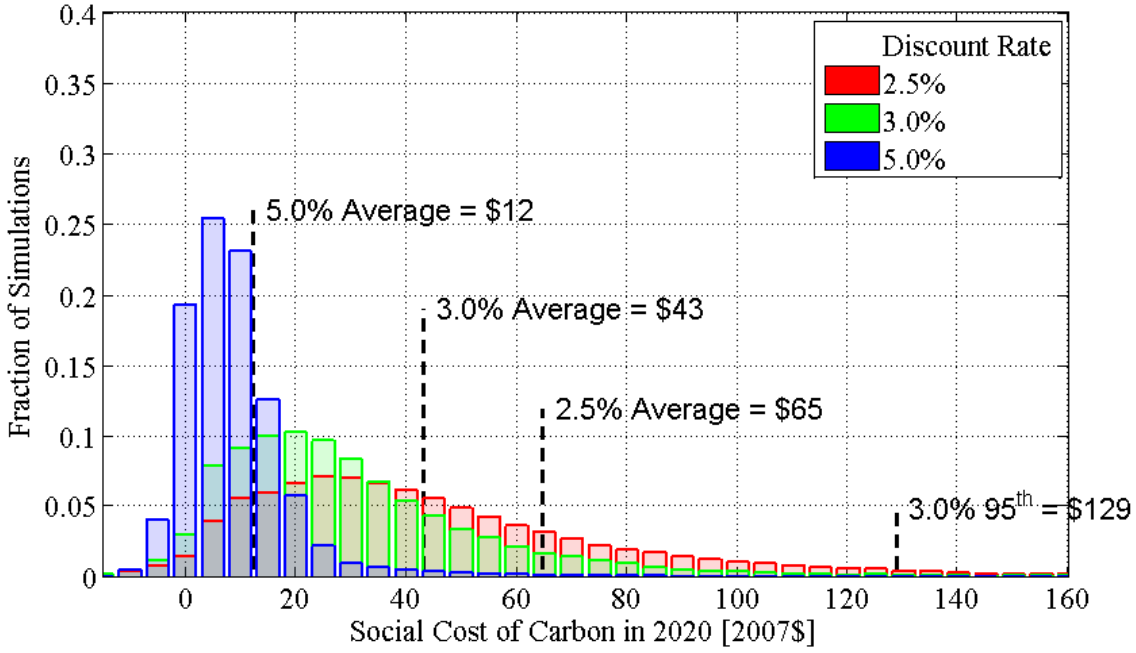
model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using linear interpolation. The full set of revised annual SCC estimates between 2010 and 2050 is reported in the Appendix.

Table 2: Revised Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per metric ton of CO_2)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	11	33	52	90
2015	12	38	58	109
2020	12	43	65	129
2025	14	48	70	144
2030	16	52	76	159
2035	19	57	81	176
2040	21	62	87	192
2045	24	66	92	206
2050	27	71	98	221

The SCC estimates using the updated versions of the models are higher than those reported in the 2010 TSD due to the changes to the models outlined in the previous section. By way of comparison, the 2020 SCC estimates reported in the original TSD were $7, $26, $42 and $81 (2007$) (Interagency Working Group on Social Cost of Carbon 2010). Figure 1 illustrates where the four SCC values for 2020 fall within the full distribution for each discount rate based on the combined set of runs for each model and scenario (150,000 estimates in total for each discount rate). In general, the distributions are skewed to the right and have long tails. The Figure also shows that the lower the discount rate, the longer the right tail of the distribution.

Figure 1: Distribution of SCC Estimates for 2020 (in 2007$ per metric ton CO_2)



As was the case in the 2010 TSD, the SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. The approach taken by the interagency group is to compute the cost of a marginal ton emitted in the future by running the models for a set of perturbation years out to 2050. Table 3 illustrates how the growth rate for these four SCC estimates varies over time.

Table 3: Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Growth Rate (%)	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010-2020	1.2%	3.2%	2.4%	4.3%
2020-2030	3.4%	2.1%	1.7%	2.4%
2030-2040	3.0%	1.8%	1.5%	2.0%
2040-2050	2.6%	1.6%	1.3%	1.5%

The future monetized value of emission reductions in each year (the SCC in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. As previously discussed in the 2010 TSD, damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency – i.e., future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate.

Under current OMB guidance contained in Circular A-4, analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the climate change problem is highly unusual in at least two respects. First, it involves a global externality: emissions of most greenhouse gases contribute to damages around

the world even when they are emitted in the United States. Consequently, to address the global nature of the problem, the SCC must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Even if the United States were to reduce its greenhouse gas emissions to zero, that step would be far from enough to avoid substantial climate change. Other countries would also need to take action to reduce emissions if significant changes in the global climate are to be avoided. Emphasizing the need for a global solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions and in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. When these considerations are taken as a whole, the interagency group concluded that a global measure of the benefits from reducing U.S. emissions is preferable. For additional discussion, see the 2010 TSD.

IV. Other Model Limitations and Research Gaps

The 2010 interagency SCC TSD discusses a number of important limitations for which additional research is needed. In particular, the document highlights the need to improve the quantification of both non-catastrophic and catastrophic damages, the treatment of adaptation and technological change, and the way in which inter-regional and inter-sectoral linkages are modeled. While the new version of the models discussed above offer some improvements in these areas, further work remains warranted. The 2010 TSD also discusses the need to more carefully assess the implications of risk aversion for SCC estimation as well as the inability to perfectly substitute between climate and non-climate goods at higher temperature increases, both of which have implications for the discount rate used. EPA, DOE, and other agencies continue to engage in research on modeling and valuation of climate impacts that can potentially improve SCC estimation in the future.

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Appendix

Table A1: Annual SCC Values: 2010-2050 (2007$/metric ton CO_2)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	11	33	52	90
2011	11	34	54	94
2012	11	35	55	98
2013	11	36	56	102
2014	11	37	57	106
2015	12	38	58	109
2016	12	39	60	113
2017	12	40	61	117
2018	12	41	62	121
2019	12	42	63	125
2020	12	43	65	129
2021	13	44	66	132
2022	13	45	67	135
2023	13	46	68	138
2024	14	47	69	141
2025	14	48	70	144
2026	15	49	71	147
2027	15	49	72	150
2028	15	50	73	153
2029	16	51	74	156
2030	16	52	76	159
2031	17	53	77	163
2032	17	54	78	166
2033	18	55	79	169
2034	18	56	80	172
2035	19	57	81	176
2036	19	58	82	179
2037	20	59	84	182
2038	20	60	85	185
2039	21	61	86	188
2040	21	62	87	192
2041	22	63	88	195
2042	22	64	89	198
2043	23	65	90	200
2044	23	65	91	203
2045	24	66	92	206
2046	24	67	94	209
2047	25	68	95	212
2048	25	69	96	215
2049	26	70	97	218
2050	27	71	98	221

Table A2: 2020 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario[12]	PAGE									
IMAGE	6	11	15	27	58	129	139	327	515	991
MERGE	4	6	9	16	34	78	82	196	317	649
MESSAGE	4	8	11	20	42	108	107	278	483	918
MiniCAM Base	5	9	12	22	47	107	113	266	431	872
5th Scenario	2	4	6	11	25	85	68	200	387	955
Scenario	DICE									
IMAGE	25	31	37	47	64	72	92	123	139	161
MERGE	14	18	20	26	36	40	50	65	74	85
MESSAGE	20	24	28	37	51	58	71	95	109	221
MiniCAM Base	20	25	29	38	53	61	76	102	117	135
5th Scenario	17	22	25	33	45	52	65	91	106	126
Scenario	FUND									
IMAGE	-17	-1	5	17	34	44	59	90	113	176
MERGE	-7	2	7	16	30	35	49	72	91	146
MESSAGE	-19	-4	2	12	27	32	46	70	87	135
MiniCAM Base	-9	1	8	18	35	45	59	87	108	172
5th Scenario	-30	-12	-5	6	19	24	35	57	72	108

Table A3: 2020 Global SCC Estimates at 3 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	4	7	10	18	38	91	95	238	385	727
MERGE	2	4	6	11	23	56	58	142	232	481
MESSAGE	3	5	7	13	29	75	74	197	330	641
MiniCAM Base	3	5	8	14	30	73	75	184	300	623
5th Scenario	1	3	4	7	17	58	48	136	264	660
Scenario	DICE									
IMAGE	16	21	24	32	43	48	60	79	90	102
MERGE	10	13	15	19	25	28	35	44	50	58
MESSAGE	14	18	20	26	35	40	49	64	73	83
MiniCAM Base	13	17	20	26	35	39	49	65	73	85
5th Scenario	12	15	17	22	30	34	43	58	67	79
Scenario	FUND									
IMAGE	-14	-3	1	9	20	25	35	54	69	111
MERGE	-8	-1	3	9	18	22	31	47	60	97
MESSAGE	-16	-5	-1	6	16	18	28	43	55	88
MiniCAM Base	-9	-1	3	10	21	27	35	53	67	107
5th Scenario	-22	-10	-5	2	10	13	20	33	42	63

[12] See 2010 TSD for a description of these scenarios.

Table A4: 2020 Global SCC Estimates at 5 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	1	2	2	5	10	28	27	71	123	244
MERGE	1	1	2	3	7	17	17	45	75	153
MESSAGE	1	1	2	4	9	24	22	60	106	216
MiniCAM Base	1	1	2	3	8	21	21	54	94	190
5th Scenario	0	1	1	2	5	18	14	41	78	208
Scenario	DICE									
IMAGE	6	8	9	11	14	15	18	22	25	27
MERGE	4	5	6	7	9	10	12	15	16	18
MESSAGE	6	7	8	10	12	13	16	20	22	25
MiniCAM Base	5	6	7	8	11	12	14	18	20	22
5th Scenario	5	6	6	8	10	11	14	17	19	21
Scenario	FUND									
IMAGE	-9	-5	-3	-1	2	3	6	11	15	25
MERGE	-6	-3	-2	0	3	4	7	12	16	27
MESSAGE	-10	-6	-4	-1	2	2	5	9	13	23
MiniCAM Base	-7	-3	-2	0	3	4	7	11	15	26
5th Scenario	-11	-7	-5	-2	0	0	3	6	8	14

Table A5: Additional Summary Statistics of 2020 Global SCC Estimates

Discount rate:	5.0%				3.0%				2.5%			
Statistic:	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis
DICE	12	26	2	15	38	409	3	24	57	1097	3	30
PAGE	22	1616	5	32	71	14953	4	22	101	29312	4	23
FUND	3	560	-170	35222	21	22487	-85	18842	36	68055	-46	13105

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CLIMATE CHANGE 2014

Synthesis Report



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Foreword, Preface and Dedication

Foreword

The Synthesis Report (SYR) distils and integrates the findings of the three Working Group contributions to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the most comprehensive assessment of climate change undertaken thus far by the IPCC: *Climate Change 2013: The Physical Science Basis*; *Climate Change 2014: Impacts, Adaptation, and Vulnerability*; and *Climate Change 2014: Mitigation of Climate Change.* The SYR also incorporates the findings of two Special Reports on *Renewable Energy Sources and Climate Change Mitigation* (2011) and on *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (2011).

The SYR confirms that human influence on the climate system is clear and growing, with impacts observed across all continents and oceans. Many of the observed changes since the 1950s are unprecedented over decades to millennia. The IPCC is now 95 percent certain that humans are the main cause of current global warming. In addition, the SYR finds that the more human activities disrupt the climate, the greater the risks of severe, pervasive and irreversible impacts for people and ecosystems, and long-lasting changes in all components of the climate system. The SYR highlights that we have the means to limit climate change and its risks, with many solutions that allow for continued economic and human development. However, stabilizing temperature increase to below 2°C relative to pre-industrial levels will require an urgent and fundamental departure from business as usual. Moreover, the longer we wait to take action, the more it will cost and the greater the technological, economic, social and institutional challenges we will face.

These and the other findings of the SYR have undoubtedly and considerably enhanced our understanding of some of the most critical issues in relation to climate change: the role of greenhouse gas emissions; the severity of potential risks and impacts, especially for the least developed countries and vulnerable communities, given their limited ability to cope; and the options available to us and their underlying requirements to ensure that the effects of climate change remain manageable. As such, the SYR calls for the urgent attention of both policymakers and citizens of the world to tackle this challenge.

The timing of the SYR, which was released on 2nd November 2014 in Copenhagen, was crucial. Policymakers met in December 2014 in Lima at the 20th Conference of Parties under the United Nations Framework Convention on Climate Change (UNFCCC) to prepare the groundwork for the 21st Session in 2015 in Paris, when they have been tasked with concluding a new agreement to deal with climate change. It is our hope that the scientific findings of the SYR will be the basis of their motivation to find the way to a global agreement which can keep climate change to a manageable level, as the SYR gives us the knowledge to make informed choices, and enhances our vital understanding of the rationale for action – and the serious implications of inaction. Ignorance can no longer be an excuse for tergiversation.

As an intergovernmental body jointly established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), the Intergovernmental Panel on Climate Change (IPCC) has provided policymakers with the most authoritative and objective scientific and technical assessments in this field. Beginning in 1990, this series of IPCC Assessment Reports, Special Reports, Technical Papers, Methodology Reports and other products have become standard works of reference.

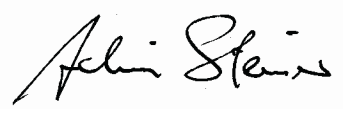
The SYR was made possible thanks to the voluntary work, dedication and commitment of thousands of experts and scientists from around the globe, representing a range of views and disciplines. We would like to express our deep gratitude to all the members of the Core Writing Team of the SYR, members of the Extended Writing Team, and the Review Editors, all of whom enthusiastically took on the huge challenge of producing an outstanding SYR on top of the other tasks they had already committed to during the AR5 cycle. We would also like to thank the staff of the Technical Support Unit of the SYR and the IPCC Secretariat for their dedication in organizing the production of this IPCC report.

We also wish to acknowledge and thank the governments of the IPCC member countries for their support of scientists in developing this report, and for their contributions to the IPCC Trust Fund to provide the essentials for participation of experts from developing countries and countries with economies in transition. We would like to express our appreciation to the government of Wallonia (Belgium) for hosting the Scoping Meeting of the SYR, to the governments of Norway, the Netherlands, Germany and Malaysia for hosting drafting sessions of the SYR, and to the government of Denmark for hosting the 40th Session of the IPCC where the SYR was approved. The generous financial support from the governments of Norway and the Netherlands, from the Korea Energy Economics Institute, and the in-kind support by the Netherlands Environmental Assessment Agency and The Energy and Resources Institute, New Delhi (India), enabled the smooth operation of the Technical Support Unit of the SYR. This is gratefully acknowledged.

We would particularly like to express our thanks to Dr Rajendra K. Pachauri, Chairman of the IPCC, for his leadership and constant guidance throughout the production of this report.



Michel Jarraud
Secretary General
World Meteorological Organization



Achim Steiner
Executive Director
United Nations Environmental Programme

Preface

The Synthesis Report (SYR), constituting the final product of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), is published under the title *Climate Change 2014.* This report distils, synthesizes and integrates the key findings of the three Working Group contributions – *The Physical Science Basis*, *Impacts, Adaptation, and Vulnerability* and *Mitigation of Climate Change* – to the AR5 in a concise document for the benefit of decision makers in the government, the private sector as well as the public at large. The SYR also draws on the findings of the two Special Reports brought out in 2011 dealing with *Renewable Energy Sources and Climate Change Mitigation*, and *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. The SYR, therefore, is a comprehensive up-to-date compilation of assessments dealing with climate change, based on the most recent scientific, technical and socio-economic literature in the field.

Scope of the Report

This document is the result of coordinated and carefully connected cross Working Group efforts to ensure coherent and comprehensive information on various aspects related to climate change. This SYR includes a consistent evaluation and assessment of uncertainties and risks; integrated costing and economic analysis; regional aspects; changes, impacts and responses related to water and earth systems, the carbon cycle including ocean acidification, cryosphere and sea level rise; as well as treatment of mitigation and adaptation options within the framework of sustainable development. Through the entire length of the SYR, information is also provided relevant to Article 2, the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC).

Other aspects of climate change covered in this report include direct impacts of climate change on natural systems as well as both direct and indirect impacts on human systems, such as human health, food security and security of societal conditions. By embedding climate change risk and issues of adaptation and mitigation within the framework of sustainable development, the SYR also highlights the fact that nearly all systems on this planet would be affected by the impacts of a changing climate, and that it is not possible to draw boundaries around climate change, its associated risks and impacts on the one hand and on the other, development which meets the needs of the present generation without compromising the ability of future generations to meet their own needs. The Report, therefore, also focuses on connections between these aspects and provides information on how climate change overlaps with and mainstreams into other developmental issues.

Structure

The Report comprises a Summary for Policymakers (SPM) and a longer report from which the SPM is derived, as well as annexes. Even though the SPM follows a structure and sequence similar to that in the longer report, some specific issues covered under more than one topic of the longer report are summarized in one particular section of the SPM. Each paragraph of the SPM contains references to the respective text in the longer report. In turn, the latter contains extensive references to relevant chapters of the underlying Working Group Reports or the two Special Reports mentioned above. The SYR is essentially self-contained, and its SPM includes the most policy relevant material drawn from the longer report and the entire AR5.

All the three contributions to the AR5 including each Summary for Policymakers, each Technical Summary, frequently asked questions as well as the Synthesis Report in all official UN languages are available online on the IPCC website and in electronic offline versions. In these electronic versions, references in the SYR to relevant parts of the underlying material are provided as hyperlinks, thereby enabling the reader to easily find further scientific, technical and socio-economic information. A user guide, glossary of terms used and listing of acronyms, authors, Review Editors and Expert Reviewers are provided in the annexes to this report.

To facilitate access to the findings of the SYR for a wide readership and to enhance their usability for stakeholders, each section of the SPM carries highlighted headline statements. Taken together, these 21 headline statements provide an overarching summary in simple and completely non-technical language for easy assimilation by readers from different walks of life. These headline statements have been crafted by the authors of the Report, and approved by the member governments of the IPCC.

The longer report is structured around four topic headings as mandated by the Panel:

Observed changes and their causes (Topic 1) integrates new information from the three Working Groups on observed changes in the climate system, including changes in the atmosphere, oceans, cryosphere and sea level; recent and past drivers and human influences affecting emission drivers; observed impacts, including changes in extreme weather and climate events; and attribution of climate changes and impacts.

Future climate changes, risks and impacts (Topic 2) presents information about future climate change, risks and impacts. It integrates information about key drivers of future climate, the relationship between cumulative emissions and temperature change, and projected changes in the climate system in the 21st century and beyond. It assesses future risks and impacts caused by a changing climate and the interaction of climate-related and other hazards. It provides information about long-term changes including sea-level rise and ocean acidification, and the risk of irreversible and abrupt changes.

Future Pathways for Adaptation, Mitigation and Sustainable Development (Topic 3) addresses future pathways for adaptation and mitigation as complementary strategies for reducing and managing the risks of climate change and assesses their interaction with sustainable development. It describes analytical approaches for effective

decision-making and differences in risks of climate change, adaptation and mitigation in terms of timescale, magnitude and persistence. It analyses the characteristics of adaptation and mitigation pathways, and associated challenges, limits and benefits, including for different levels of future warming.

Adaptation and Mitigation (Topic 4) brings together information from Working Groups II and III on specific adaptation and mitigation options, including environmentally sound technologies and infrastructure, sustainable livelihoods, behaviour and lifestyle choices. It describes common enabling factors and constraints, and policy approaches, finance and technology on which effective response measures depend. It shows opportunities for integrated responses and links adaptation and mitigation with other societal objectives.

Process

The SYR of the AR5 of the IPCC has been prepared in accordance with the procedures of the IPCC to ensure adequate effort and rigor being achieved in the process. For the AR5 the preparation of the SYR was taken in hand a year earlier than was the case with the Fourth Assessment Report (AR4) – while the Working Group Reports were still being completed – with a view to enhancing integration and ensuring adequate synthesis. A scoping meeting specifically for proposing the detailed outline of the AR5 Synthesis Report was held in Liège, Belgium in August, 2010, and the outline produced in that meeting was approved by the Panel in October, 2010 in Busan, Republic of Korea. In accordance with IPCC procedures, the IPCC Chair in consultation with the Co-Chairs of the Working Groups nominated authors for the Core Writing Team (CWT) of the SYR and a total of 45 CWT members and 9 Review Editors were selected and accepted by the IPCC Bureau in March, 2012. In addition, 14 Extended Writing Team (EWT) authors were selected by the CWT with the approval of the Chair of the IPCC, and this latter group contributed substantially to the material and the text provided in this report. During evolution of the contents of the SYR the IPCC Bureau was approached and it approved the inclusion of 6 additional CWT members and an additional Review Editor. This further enhanced and deepened the expertise required for the preparation of the Report. The final draft report which has undergone a combined review by experts and governments was submitted to the 40th Session of the IPCC, held from 27 October to 1 November 2014 in Copenhagen, Denmark, where governments approved the SPM line by line and adopted the longer report section by section.

Acknowledgements

Our profound gratitude and deep indebtedness goes to the members of the Core Writing Team and the substantial help from the Extended Writing Team members, for their tireless efforts, expertise, and amazing level of dedication throughout the production of the SYR. The SYR could not have been completed successfully without their inspirational commitment to excellence and integrity, and their meticulous attention to detail. We also wish to thank the Review Editors for their invaluable help ensuring that the SYR provides a balanced and complete assessment of current information relevant to climate change. Their role was crucial to ensure transparency of the process which the IPCC can pride itself on. Our thanks go also to all authors of the AR5 and the two Special Reports because without their careful assessment of the huge body of literature on various aspects of climate change and their comments on the draft report, the preparation of the SYR would not have been possible.

Throughout the AR5, we benefitted greatly from the wisdom and insight of our colleagues in the IPCC leadership, especially Dr Thomas Stocker and Dr Qin Dahe, Working Group I Co-Chairs; Dr Chris Field and Dr Vicente Barros, Working Group II Co-Chairs; and Dr Ottmar Edenhofer, Dr Ramón Pichs-Madruga and Dr Youba Sokona, Working Group III Co-Chairs. Their cooperation on issues related to knowledge from the reports of all three Working Groups was a definite asset for the production of a high-quality final document.

We also wish to thank Fredolin Tangang, David Wratt, Eduardo Calvo, Jose Moreno, Jim Skea and Suzana Kahn Ribeiro, who acted as Review Editors during the Approval Session of the SYR, ensuring that the edits made to the SPM during the Session were correctly reflected in the longer report. Their important work guaranteed the high level of trust between the scientists and the governments, enabling them to work smoothly in symbiosis, which is a unique feature of the IPCC and its credibility.

We extend our deep appreciation of the enthusiasm, dedication and professional contributions of Gian-Kasper Plattner, Melinda Tignor and Judith Boschung from the Technical Support Unit of Working Group I, Katie Mach and Eren Bilir from the Technical Support Unit of Working Group II, Ellie Farahani, Jussi Savolainen and Steffen Schlömer from the Technical Support Unit of Working Group III, and Gerrit Hansen from the Potsdam Institute for Climate Impact Research during the Approval Session of the SYR, working as a team with the Technical Support Unit of the SYR, which was indispensable in the successful outcomes of the Session. A special thanks goes to Adrien Michel from the Technical Support Unit of Working Group I for his work on the SYR figures.

Our thanks go to Leo Meyer, Head of the Technical Support Unit of the Synthesis Report, and the members of the Technical Support Unit Sander Brinkman, Line van Kesteren, Noemie Leprince-Ringuet and Fijke van Boxmeer for their capacity to expand their strengths and carry out the mammoth task of coordinating the development and production of the SYR. Each one of them put in tireless efforts, displaying deep commitment and dedication to ensure the production of an outstanding SYR.

We would like to acknowledge the work and innumerable tasks performed in support of the preparation, release and publication of the Report by the staff of the IPCC Secretariat: Gaetano Leone, Carlos Martin-Novella, Jonathan Lynn, Brenda Abrar-Milani, Jesbin Baidya, Laura Biagioni, Mary Jean Burer, Annie Courtin, Judith Ewa, Joelle Fernandez, Nina Peeva, Sophie Schlingemann, Amy Smith and Werani Zabula. Thanks are also due to Francis Hayes and Elhousseine Gouaini for acting as conference officers at the approval Session.

We are appreciative of the member governments of the IPCC who graciously hosted the SYR scoping meeting, four of our Core Writing Meetings and the 40th Session of the IPCC: Belgium, Norway, The Netherlands, Germany, Malaysia and Denmark. We express our thanks

to the governments, WMO, UNEP and the UNFCCC for their contributions to the Trust Fund which supported various elements of expenditure. We wish to particularly thank the Governments of Norway and The Netherlands, and the Korea Energy Economics Institute for their generous financial support of the SYR Technical Support Unit, and The Netherlands Environmental Assessment Agency PBL and The Energy and Resources Institute, New Delhi, for their in-kind support of the SYR Technical Support Unit. We also acknowledge the support of IPCC's parent organizations, UNEP and WMO, and particularly WMO for hosting the IPCC Secretariat and our first Core Writing Team meeting. May we convey our deep gratitude to the UNFCCC for their cooperation at various stages of this enterprise and for the prominence they give to our work in several appropriate fora.



R.K. Pachauri
Chairman of the IPCC



Renate Christ
Secretary of the IPCC

Dedication



Stephen H. Schneider
(11 February 1945 – 19 July 2010)

The Synthesis Report of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) is dedicated to the memory of Stephen H. Schneider, one of the foremost climate scientists of our time.

Steve Schneider, born in New York, trained as a plasma physicist, embraced scholarship in the field of climate science almost 40 years ago and continued his relentless efforts creating new knowledge in the field and informing policymakers and the public at large on the growing problem of climate change and solutions for dealing with it. At all times Steve Schneider remained intrepid and forthright in expressing his views. His convictions were driven by the strength of his outstanding scientific expertise. He was highly respected as Founding Editor of the interdisciplinary journal *Climatic Change* and authored hundreds of books and papers, many of which were co-authored with scientists from diverse disciplines. His association with the IPCC began with the First Assessment Report which was published in 1990, and which played a major role in the scientific foundation of the UN Framework Convention on Climate Change. Subsequently, he was Lead Author, Coordinating Lead Author and Expert Reviewer for various Assessment Reports and a member of the Core Writing Team for the Synthesis Report of the Fourth Assessment Report. His life and accomplishments have inspired and motivated members of the Core Writing Team of this Report. Steve Schneider's knowledge was a rare synthesis of several disciplines which are an essential part of the diversity inherent in climate science.

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In the Summary for Policymakers, the references refer to the numbers of the sections, figures, tables and boxes in the underlying Introduction and Topics of this Synthesis Report.

In the Introduction and Topics of the longer report, the references refer to the contributions of the Working Groups I, II and III (WGI, WGII, WGIII) to the Fifth Assessment Report and other IPCC Reports (in italicized curly brackets), or to other sections of the Synthesis Report itself (in round brackets).

The following abbreviations have been used:
SPM: Summary for Policymakers
TS: Technical Summary
ES: Executive Summary of a chapter
Numbers denote specific chapters and sections of a report.

Other IPCC reports cited in this Synthesis Report:
SREX: Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
SRREN: Special Report on Renewable Energy Sources and Climate Change Mitigation
AR4: Fourth Assessment Report

Climate Change 2014
Synthesis Report
Summary for Policymakers

Introduction

This Synthesis Report is based on the reports of the three Working Groups of the Intergovernmental Panel on Climate Change (IPCC), including relevant Special Reports. It provides an integrated view of climate change as the final part of the IPCC's Fifth Assessment Report (AR5).

This summary follows the structure of the longer report which addresses the following topics: Observed changes and their causes; Future climate change, risks and impacts; Future pathways for adaptation, mitigation and sustainable development; Adaptation and mitigation.

In the Synthesis Report, the certainty in key assessment findings is communicated as in the Working Group Reports and Special Reports. It is based on the author teams' evaluations of underlying scientific understanding and is expressed as a qualitative level of confidence (from *very low* to *very high*) and, when possible, probabilistically with a quantified likelihood (from *exceptionally unlikely* to *virtually certain*)[1]. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers.

This report includes information relevant to Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC).

SPM 1. Observed Changes and their Causes

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems. *{1}*

SPM 1.1 Observed changes in the climate system

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen. *{1.1}*

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period from 1983 to 2012 was *likely* the warmest 30-year period of the last 1400 years in the Northern Hemisphere, where such assessment is possible (*medium confidence*). The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06] °C[2] over the period 1880 to 2012, when multiple independently produced datasets exist (Figure SPM.1a). *{1.1.1, Figure 1.1}*

In addition to robust multi-decadal warming, the globally averaged surface temperature exhibits substantial decadal and interannual variability (Figure SPM.1a). Due to this natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. As one example, the rate of warming over

[1] Each finding is grounded in an evaluation of underlying evidence and agreement. In many cases, a synthesis of evidence and agreement supports an assignment of confidence. The summary terms for evidence are: limited, medium or robust. For agreement, they are low, medium or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, e.g., *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, more unlikely than likely 0–<50%, extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*. See for more details: Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L. Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.-K. Plattner, G.W. Yohe and F.W. Zwiers, 2010: Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties, Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland, 4 pp.

[2] Ranges in square brackets or following '±' are expected to have a 90% likelihood of including the value that is being estimated, unless otherwise stated.

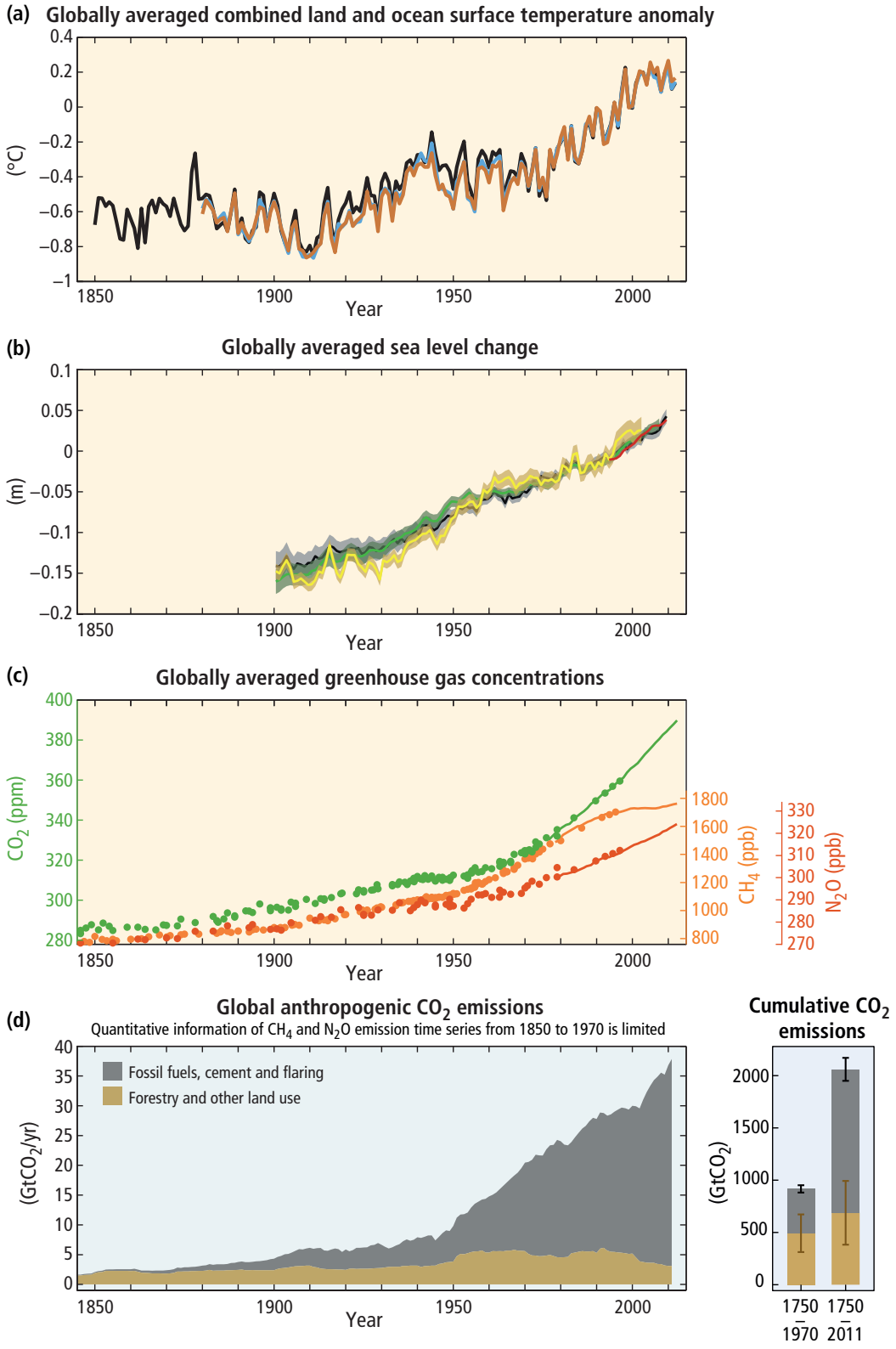


Figure SPM.1 | The complex relationship between the observations (panels a, b, c, yellow background) and the emissions (panel d, light blue background) is addressed in Section 1.2 and Topic 1. Observations and other indicators of a changing global climate system. Observations: **(a)** Annually and globally averaged combined land and ocean surface temperature anomalies relative to the average over the period 1986 to 2005. Colours indicate different data sets. **(b)** Annually and globally averaged sea level change relative to the average over the period 1986 to 2005 in the longest-running dataset. Colours indicate different data sets. All datasets are aligned to have the same value in 1993, the first year of satellite altimetry data (red). Where assessed, uncertainties are indicated by coloured shading. **(c)** Atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2, green), methane (CH_4, orange) and nitrous oxide (N_2O, red) determined from ice core data (dots) and from direct atmospheric measurements (lines). Indicators: **(d)** Global anthropogenic CO_2 emissions from forestry and other land use as well as from burning of fossil fuel, cement production and flaring. Cumulative emissions of CO_2 from these sources and their uncertainties are shown as bars and whiskers, respectively, on the right hand side. The global effects of the accumulation of CH_4 and N_2O emissions are shown in panel c. Greenhouse gas emission data from 1970 to 2010 are shown in Figure SPM.2. *{Figures 1.1, 1.3, 1.5}*

the past 15 years (1998–2012; 0.05 [–0.05 to 0.15] °C per decade), which begins with a strong El Niño, is smaller than the rate calculated since 1951 (1951–2012; 0.12 [0.08 to 0.14] °C per decade). *{1.1.1, Box 1.1}*

Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*), with only about 1% stored in the atmosphere. On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 [0.09 to 0.13] °C per decade over the period 1971 to 2010. It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010, and it *likely* warmed between the 1870s and 1971. *{1.1.2, Figure 1.2}*

Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (*medium confidence* before and *high confidence* after 1951). For other latitudes, area-averaged long-term positive or negative trends have *low confidence*. Observations of changes in ocean surface salinity also provide indirect evidence for changes in the global water cycle over the ocean (*medium confidence*). It is *very likely* that regions of high salinity, where evaporation dominates, have become more saline, while regions of low salinity, where precipitation dominates, have become fresher since the 1950s. *{1.1.1, 1.1.2}*

Since the beginning of the industrial era, oceanic uptake of CO_2 has resulted in acidification of the ocean; the pH of ocean surface water has decreased by 0.1 (*high confidence*), corresponding to a 26% increase in acidity, measured as hydrogen ion concentration. *{1.1.2}*

Over the period 1992 to 2011, the Greenland and Antarctic ice sheets have been losing mass (*high confidence*), *likely* at a larger rate over 2002 to 2011. Glaciers have continued to shrink almost worldwide (*high confidence*). Northern Hemisphere spring snow cover has continued to decrease in extent (*high confidence*). There is *high confidence* that permafrost temperatures have increased in most regions since the early 1980s in response to increased surface temperature and changing snow cover. *{1.1.3}*

The annual mean Arctic sea-ice extent decreased over the period 1979 to 2012, with a rate that was *very likely* in the range 3.5 to 4.1% per decade. Arctic sea-ice extent has decreased in every season and in every successive decade since 1979, with the most rapid decrease in decadal mean extent in summer (*high confidence*). It is *very likely* that the annual mean Antarctic sea-ice extent increased in the range of 1.2 to 1.8% per decade between 1979 and 2012. However, there is *high confidence* that there are strong regional differences in Antarctica, with extent increasing in some regions and decreasing in others. *{1.1.3, Figure 1.1}*

Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m (Figure SPM.1b). The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*). *{1.1.4, Figure 1.1}*

SPM 1.2 Causes of climate change

Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are *extremely likely* to have been the dominant cause of the observed warming since the mid-20th century. ***{1.2, 1.3.1}***

Anthropogenic greenhouse gas (GHG) emissions since the pre-industrial era have driven large increases in the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Figure SPM.1c). Between 1750 and 2011, cumulative anthropogenic CO_2 emissions to the atmosphere were 2040 ± 310 $GtCO_2$. About 40% of these emissions have remained in the atmosphere (880 ± 35 $GtCO_2$); the rest was removed from the atmosphere and stored on land (in plants and soils) and in the ocean. The ocean has absorbed about 30% of the emitted anthropogenic CO_2, causing ocean acidification. About half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years (*high confidence*) (Figure SPM.1d). *{1.2.1, 1.2.2}*

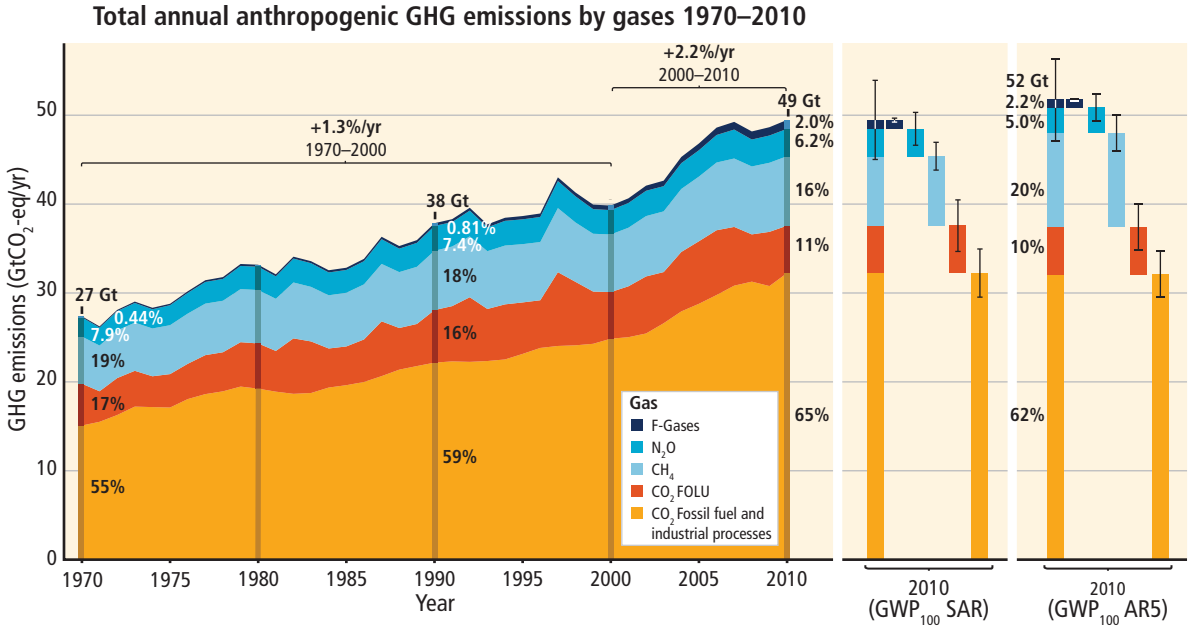


Figure SPM.2 | Total annual anthropogenic greenhouse gas (GHG) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) for the period 1970 to 2010 by gases: CO_2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH_4); nitrous oxide (N_2O); fluorinated gases covered under the Kyoto Protocol (F-gases). Right hand side shows 2010 emissions, using alternatively CO_2-equivalent emission weightings based on IPCC Second Assessment Report (SAR) and AR5 values. Unless otherwise stated, CO_2-equivalent emissions in this report include the basket of Kyoto gases (CO_2, CH_4, N_2O as well as F-gases) calculated based on 100-year Global Warming Potential (GWP_{100}) values from the SAR (see Glossary). Using the most recent GWP_{100} values from the AR5 (right-hand bars) would result in higher total annual GHG emissions (52 $GtCO_2$-eq/yr) from an increased contribution of methane, but does not change the long-term trend significantly. *{Figure 1.6, Box 3.2}*

Total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute increases between 2000 and 2010, despite a growing number of climate change mitigation policies. Anthropogenic GHG emissions in 2010 have reached 49 ± 4.5 $GtCO_2$-eq/yr [3]. Emissions of CO_2 from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emissions increase from 1970 to 2010, with a similar percentage contribution for the increase during the period 2000 to 2010 (*high confidence*) (Figure SPM.2). Globally, economic and population growth continued to be the most important drivers of increases in CO_2 emissions from fossil fuel combustion. The contribution of population growth between 2000 and 2010 remained roughly identical to the previous three decades, while the contribution of economic growth has risen sharply. Increased use of coal has reversed the long-standing trend of gradual decarbonization (i.e., reducing the carbon intensity of energy) of the world's energy supply (*high confidence*). *{1.2.2}*

The evidence for human influence on the climate system has grown since the IPCC Fourth Assessment Report (AR4). It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period (Figure SPM.3). Anthropogenic forcings have *likely* made a substantial contribution to surface temperature increases since the mid-20th century over every continental region except Antarctica[4]. Anthropogenic influences have *likely* affected the global water cycle since 1960 and contributed to the retreat of glaciers since the 1960s and to the increased surface melting of the Greenland ice sheet since 1993. Anthropogenic influences have *very likely* contributed to Arctic sea-ice loss since 1979 and have *very likely* made a substantial contribution to increases in global upper ocean heat content (0–700 m) and to global mean sea level rise observed since the 1970s. *{1.3, Figure 1.10}*

[3] Greenhouse gas emissions are quantified as CO_2-equivalent ($GtCO_2$-eq) emissions using weightings based on the 100-year Global Warming Potentials, using IPCC Second Assessment Report values unless otherwise stated. *{Box 3.2}*

[4] For Antarctica, large observational uncertainties result in *low confidence* that anthropogenic forcings have contributed to the observed warming averaged over available stations.

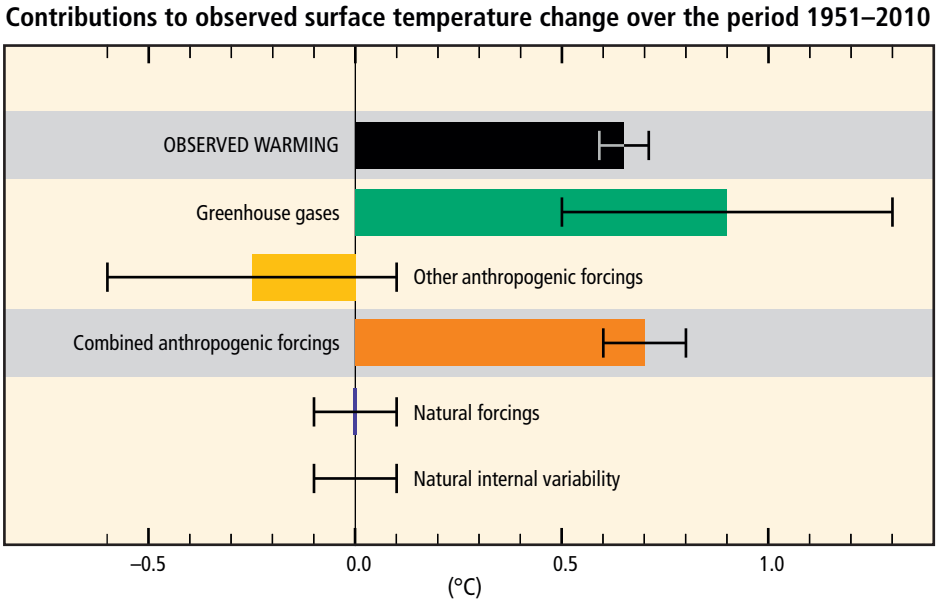


Figure SPM.3 | Assessed *likely* ranges (whiskers) and their mid-points (bars) for warming trends over the 1951–2010 period from well-mixed greenhouse gases, other anthropogenic forcings (including the cooling effect of aerosols and the effect of land use change), combined anthropogenic forcings, natural forcings and natural internal climate variability (which is the element of climate variability that arises spontaneously within the climate system even in the absence of forcings). The observed surface temperature change is shown in black, with the 5 to 95% uncertainty range due to observational uncertainty. The attributed warming ranges (colours) are based on observations combined with climate model simulations, in order to estimate the contribution of an individual external forcing to the observed warming. The contribution from the combined anthropogenic forcings can be estimated with less uncertainty than the contributions from greenhouse gases and from other anthropogenic forcings separately. This is because these two contributions partially compensate, resulting in a combined signal that is better constrained by observations. *{Figure 1.9}*

SPM 1.3 Impacts of climate change

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate. *{1.3.2}*

Evidence of observed climate change impacts is strongest and most comprehensive for natural systems. In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality (*medium confidence*). Many terrestrial, freshwater and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances and species interactions in response to ongoing climate change (*high confidence*). Some impacts on human systems have also been attributed to climate change, with a major or minor contribution of climate change distinguishable from other influences (Figure SPM.4). Assessment of many studies covering a wide range of regions and crops shows that negative impacts of climate change on crop yields have been more common than positive impacts (*high confidence*). Some impacts of ocean acidification on marine organisms have been attributed to human influence (*medium confidence*). *{1.3.2}*

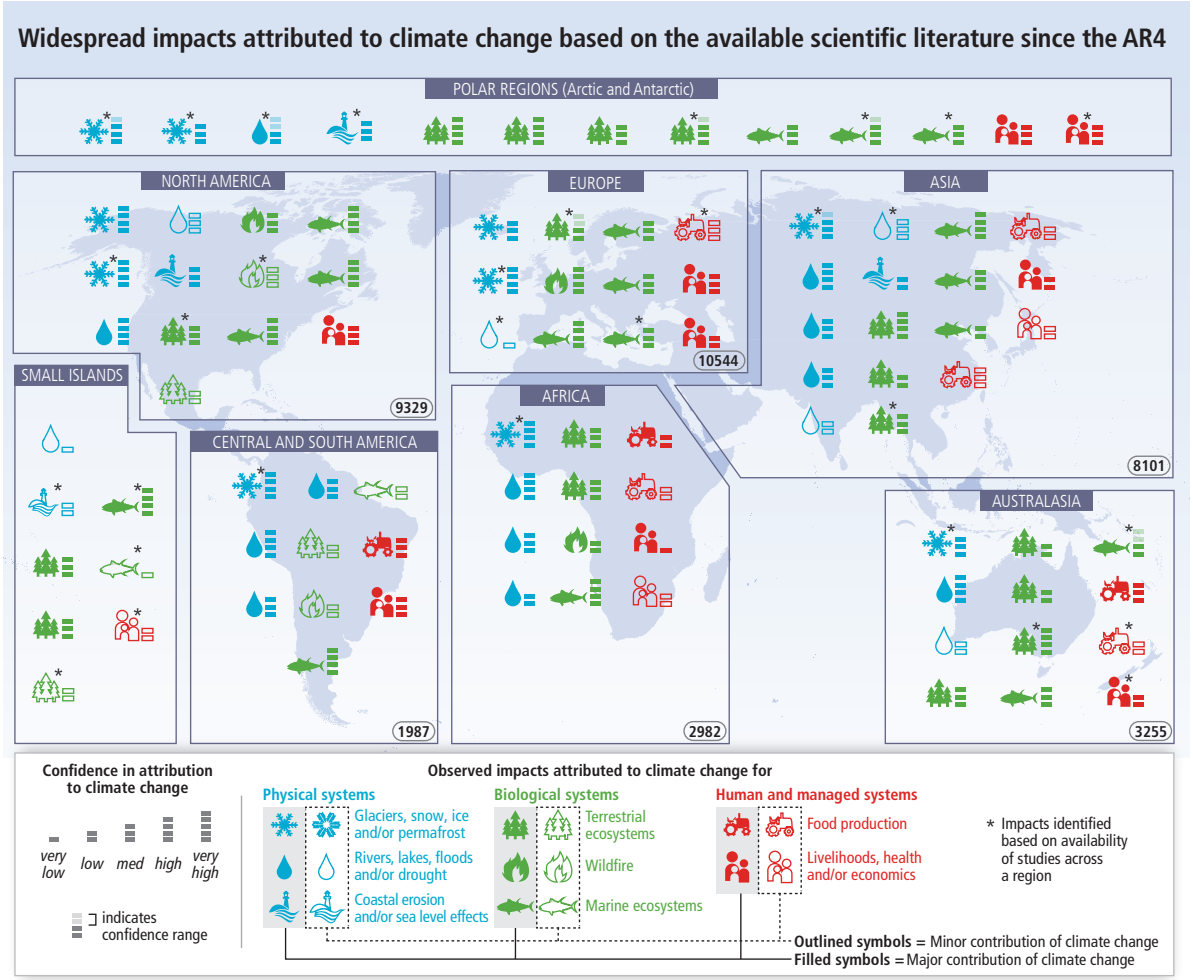


Figure SPM.4 | Based on the available scientific literature since the IPCC Fourth Assessment Report (AR4), there are substantially more impacts in recent decades now attributed to climate change. Attribution requires defined scientific evidence on the role of climate change. Absence from the map of additional impacts attributed to climate change does not imply that such impacts have not occurred. The publications supporting attributed impacts reflect a growing knowledge base, but publications are still limited for many regions, systems and processes, highlighting gaps in data and studies. Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact and confidence in attribution. Each symbol refers to one or more entries in WGII Table SPM.A1, grouping related regional-scale impacts. Numbers in ovals indicate regional totals of climate change publications from 2001 to 2010, based on the Scopus bibliographic database for publications in English with individual countries mentioned in title, abstract or key words (as of July 2011). These numbers provide an overall measure of the available scientific literature on climate change across regions; they do not indicate the number of publications supporting attribution of climate change impacts in each region. Studies for polar regions and small islands are grouped with neighbouring continental regions. The inclusion of publications for assessment of attribution followed IPCC scientific evidence criteria defined in WGII Chapter 18. Publications considered in the attribution analyses come from a broader range of literature assessed in the WGII AR5. See WGII Table SPM.A1 for descriptions of the attributed impacts. *{Figure 1.11}*

SPM 1.4 Extreme events

Changes in many extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events in a number of regions. *{1.4}*

It is *very likely* that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is *likely* that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. It is

very likely that human influence has contributed to the observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century. It is *likely* that human influence has more than doubled the probability of occurrence of heat waves in some locations. There is *medium confidence* that the observed warming has increased heat-related human mortality and decreased cold-related human mortality in some regions. *{1.4}*

There are *likely* more land regions where the number of heavy precipitation events has increased than where it has decreased. Recent detection of increasing trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at regional scale (*medium confidence*). It is *likely* that extreme sea levels (for example, as experienced in storm surges) have increased since 1970, being mainly a result of rising mean sea level. *{1.4}*

Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability (*very high confidence*). *{1.4}*

SPM 2. Future Climate Changes, Risks and Impacts

Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks. *{2}*

SPM 2.1 Key drivers of future climate

Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. Projections of greenhouse gas emissions vary over a wide range, depending on both socio-economic development and climate policy. *{2.1}*

Anthropogenic GHG emissions are mainly driven by population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy. The Representative Concentration Pathways (RCPs), which are used for making projections based on these factors, describe four different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). Scenarios without additional efforts to constrain emissions ('baseline scenarios') lead to pathways ranging between RCP6.0 and RCP8.5 (Figure SPM.5a). RCP2.6 is representative of a scenario that aims to keep global warming *likely* below 2°C above pre-industrial temperatures. The RCPs are consistent with the wide range of scenarios in the literature as assessed by WGIII[5]. *{2.1, Box 2.2, 4.3}*

Multiple lines of evidence indicate a strong, consistent, almost linear relationship between cumulative CO_2 emissions and projected global temperature change to the year 2100 in both the RCPs and the wider set of mitigation scenarios analysed in WGIII (Figure SPM.5b). Any given level of warming is associated with a range of cumulative CO_2 emissions[6], and therefore, e.g., higher emissions in earlier decades imply lower emissions later. *{2.2.5, Table 2.2}*

[5] Roughly 300 baseline scenarios and 900 mitigation scenarios are categorized by CO_2-equivalent concentration (CO_2-eq) by 2100. The CO_2-eq includes the forcing due to all GHGs (including halogenated gases and tropospheric ozone), aerosols and albedo change.

[6] Quantification of this range of CO_2 emissions requires taking into account non-CO_2 drivers.

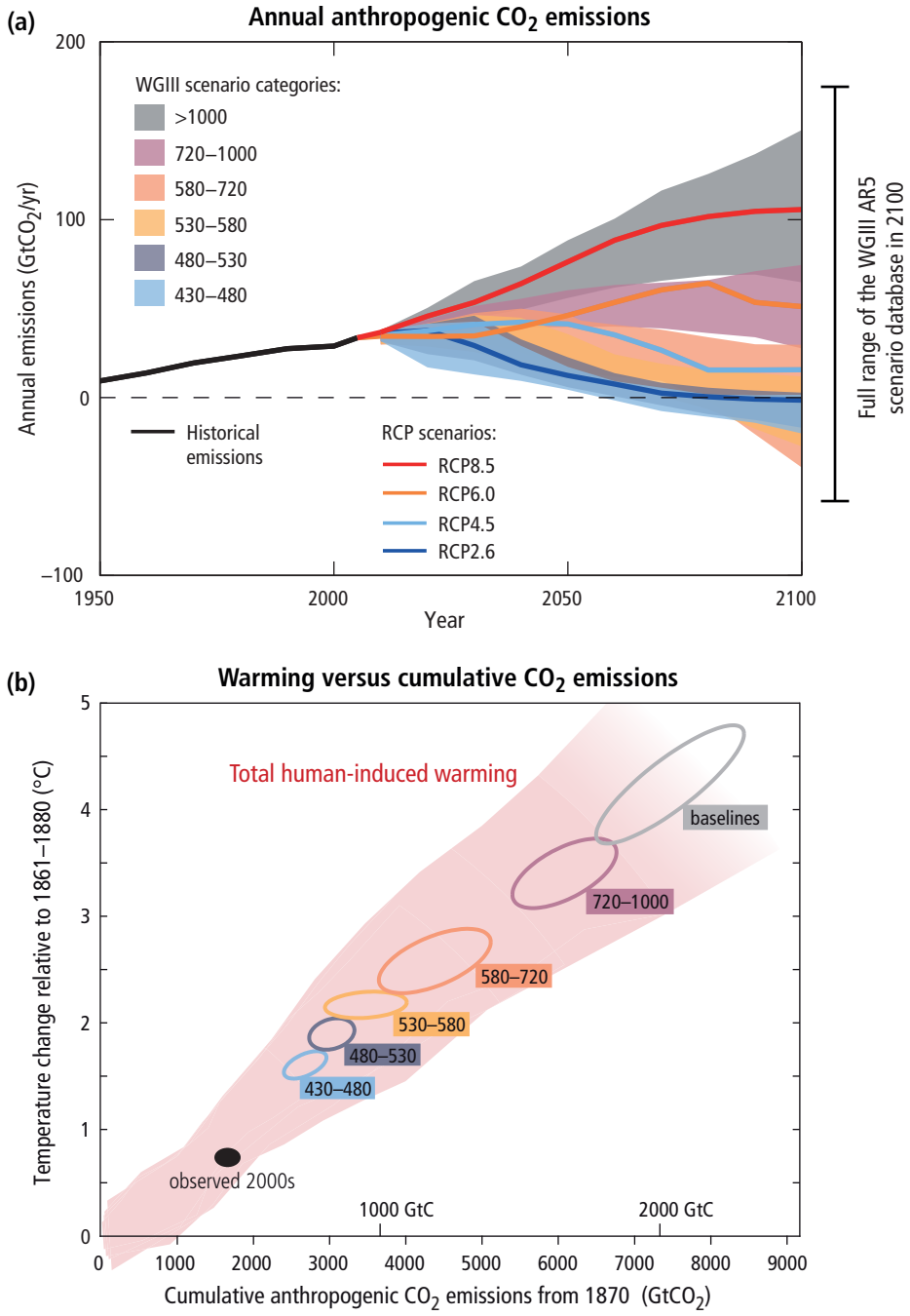


Figure SPM.5 | **(a)** Emissions of carbon dioxide (CO_2) alone in the Representative Concentration Pathways (RCPs) (lines) and the associated scenario categories used in WGIII (coloured areas show 5 to 95% range). The WGIII scenario categories summarize the wide range of emission scenarios published in the scientific literature and are defined on the basis of CO_2-eq concentration levels (in ppm) in 2100. The time series of other greenhouse gas emissions are shown in Box 2.2, Figure 1. **(b)** Global mean surface temperature increase at the time global CO_2 emissions reach a given net cumulative total, plotted as a function of that total, from various lines of evidence. Coloured plume shows the spread of past and future projections from a hierarchy of climate-carbon cycle models driven by historical emissions and the four RCPs over all times out to 2100, and fades with the decreasing number of available models. Ellipses show total anthropogenic warming in 2100 versus cumulative CO_2 emissions from 1870 to 2100 from a simple climate model (median climate response) under the scenario categories used in WGIII. The width of the ellipses in terms of temperature is caused by the impact of different scenarios for non-CO_2 climate drivers. The filled black ellipse shows observed emissions to 2005 and observed temperatures in the decade 2000–2009 with associated uncertainties. *{Box 2.2, Figure 1; Figure 2.3}*

Multi-model results show that limiting total human-induced warming to less than 2°C relative to the period 1861–1880 with a probability of >66%[7] would require cumulative CO_2 emissions from all anthropogenic sources since 1870 to remain below about 2900 $GtCO_2$ (with a range of 2550 to 3150 $GtCO_2$ depending on non-CO_2 drivers). About 1900 $GtCO_2$[8] had already been emitted by 2011. For additional context see Table 2.2. *{2.2.5}*

SPM 2.2 Projected changes in the climate system

Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is *very likely* that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise. *{2.2}*

The projected changes in Section SPM 2.2 are for 2081–2100 relative to 1986–2005, unless otherwise indicated.

Future climate will depend on committed warming caused by past anthropogenic emissions, as well as future anthropogenic emissions and natural climate variability. The global mean surface temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four RCPs and will *likely* be in the range 0.3°C to 0.7°C (*medium confidence*). This assumes that there will be no major volcanic eruptions or changes in some natural sources (e.g., CH_4 and N_2O), or unexpected changes in total solar irradiance. By mid-21st century, the magnitude of the projected climate change is substantially affected by the choice of emissions scenario. *{2.2.1, Table 2.1}*

Relative to 1850–1900, global surface temperature change for the end of the 21st century (2081–2100) is projected to *likely* exceed 1.5°C for RCP4.5, RCP6.0 and RCP8.5 (*high confidence*). Warming is *likely* to exceed 2°C for RCP6.0 and RCP8.5 (*high confidence*), *more likely than not* to exceed 2°C for RCP4.5 (*medium confidence*), but *unlikely* to exceed 2°C for RCP2.6 (*medium confidence*). *{2.2.1}*

The increase of global mean surface temperature by the end of the 21st century (2081–2100) relative to 1986–2005 is *likely* to be 0.3°C to 1.7°C under RCP2.6, 1.1°C to 2.6°C under RCP4.5, 1.4°C to 3.1°C under RCP6.0 and 2.6°C to 4.8°C under RCP8.5[9]. The Arctic region will continue to warm more rapidly than the global mean (Figure SPM.6a, Figure SPM.7a). *{2.2.1, Figure 2.1, Figure 2.2, Table 2.1}*

It is *virtually certain* that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases. It is *very likely* that heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur. *{2.2.1}*

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[7] Corresponding figures for limiting warming to 2°C with a probability of >50% and >33% are 3000 $GtCO_2$ (range of 2900 to 3200 $GtCO_2$) and 3300 $GtCO_2$ (range of 2950 to 3800 $GtCO_2$) respectively. Higher or lower temperature limits would imply larger or lower cumulative emissions respectively.

[8] This corresponds to about two thirds of the 2900 $GtCO_2$ that would limit warming to less than 2°C with a probability of >66%; to about 63% of the total amount of 3000 $GtCO_2$ that would limit warming to less than 2°C with a probability of >50%; and to about 58% of the total amount of 3300 $GtCO_2$ that would limit warming to less than 2°C with a probability of >33%.

[9] The period 1986–2005 is approximately 0.61 [0.55 to 0.67] °C warmer than 1850–1900. *{2.2.1}*

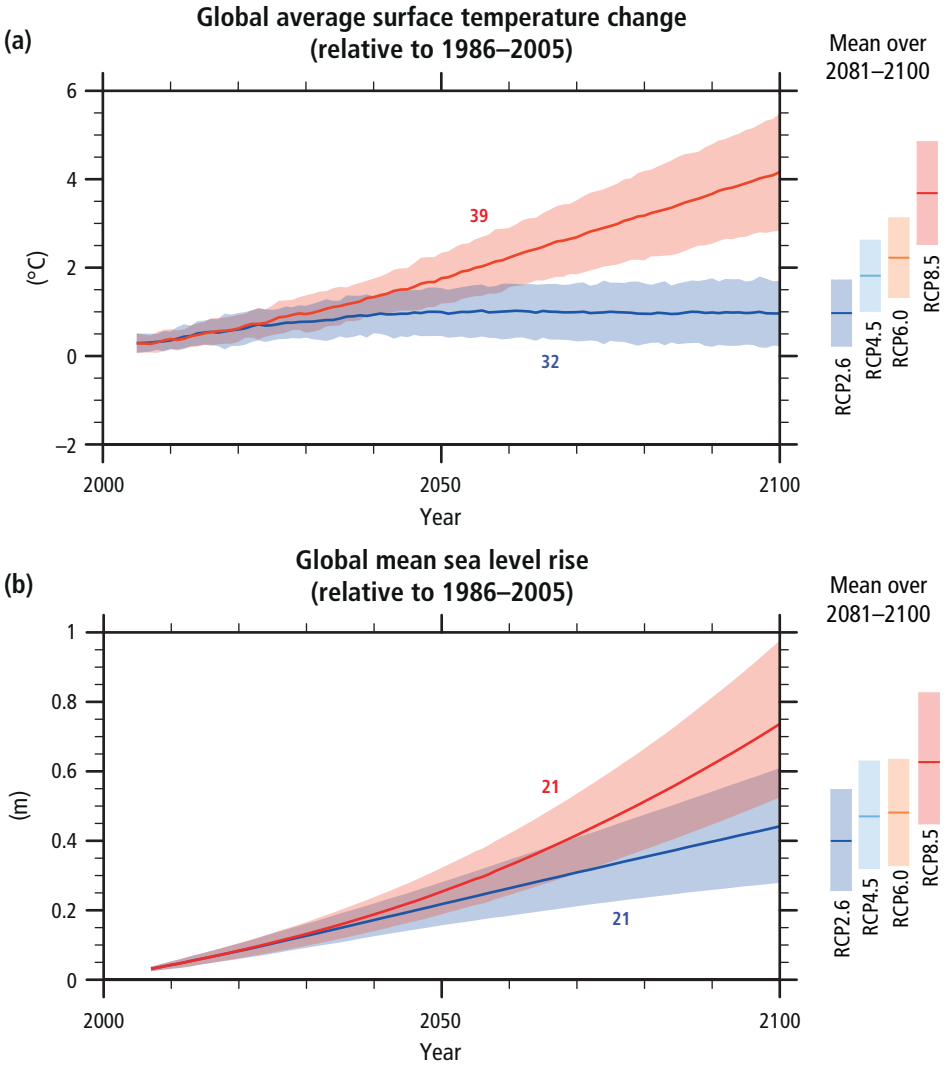


Figure SPM.6 | Global average surface temperature change **(a)** and global mean sea level rise[10] **(b)** from 2006 to 2100 as determined by multi-model simulations. All changes are relative to 1986–2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). The mean and associated uncertainties averaged over 2081–2100 are given for all RCP scenarios as coloured vertical bars at the right hand side of each panel. The number of Coupled Model Intercomparison Project Phase 5 (CMIP5) models used to calculate the multi-model mean is indicated. *{2.2, Figure 2.1}*

Changes in precipitation will not be uniform. The high latitudes and the equatorial Pacific are *likely* to experience an increase in annual mean precipitation under the RCP8.5 scenario. In many mid-latitude and subtropical dry regions, mean precipitation will *likely* decrease, while in many mid-latitude wet regions, mean precipitation will *likely* increase under the RCP8.5 scenario (Figure SPM.7b). Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will *very likely* become more intense and more frequent. *{2.2.2, Figure 2.2}*

The global ocean will continue to warm during the 21st century, with the strongest warming projected for the surface in tropical and Northern Hemisphere subtropical regions (Figure SPM.7a). *{2.2.3, Figure 2.2}*

[10] Based on current understanding (from observations, physical understanding and modelling), only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. There is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century.

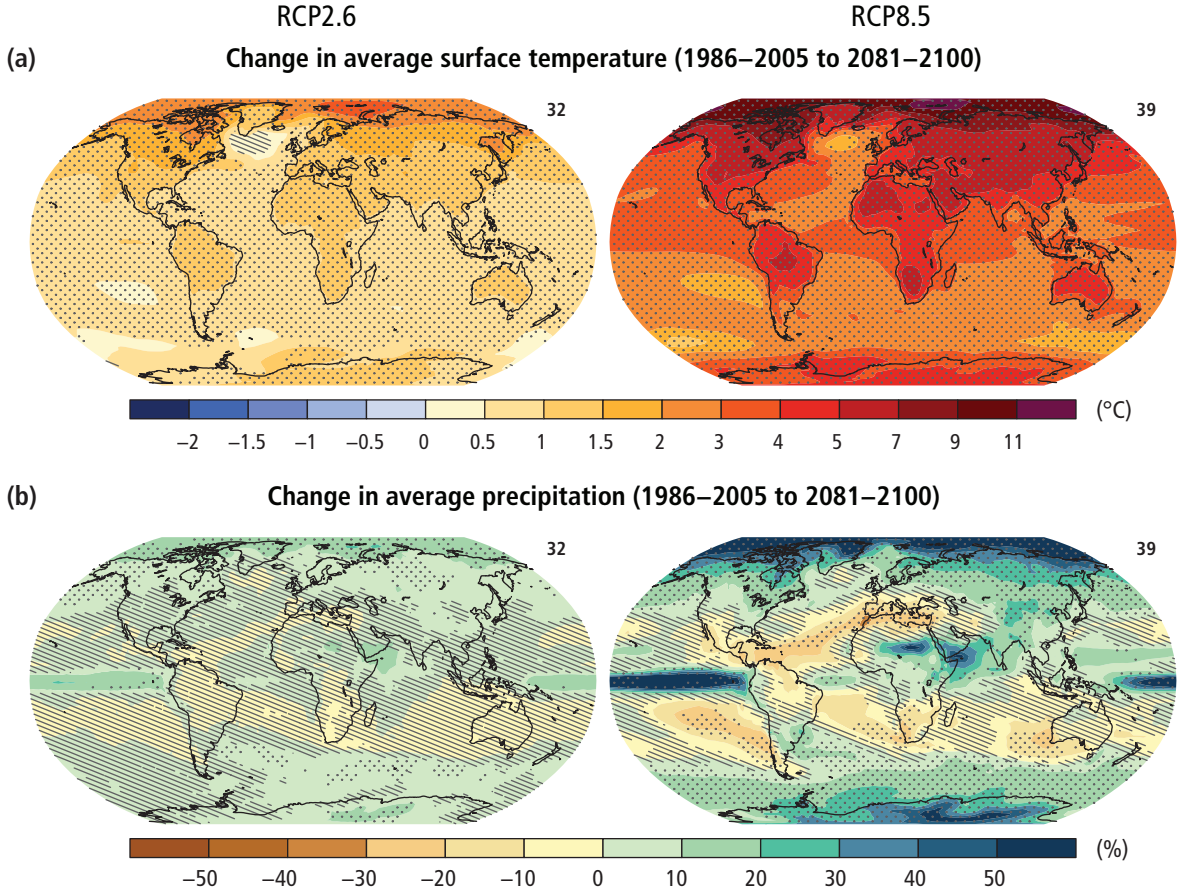


Figure SPM.7 | Change in average surface temperature **(a)** and change in average precipitation **(b)** based on multi-model mean projections for 2081–2100 relative to 1986–2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios. The number of models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Stippling (i.e., dots) shows regions where the projected change is large compared to natural internal variability and where at least 90% of models agree on the sign of change. Hatching (i.e., diagonal lines) shows regions where the projected change is less than one standard deviation of the natural internal variability. *{2.2, Figure 2.2}*

Earth System Models project a global increase in ocean acidification for all RCP scenarios by the end of the 21st century, with a slow recovery after mid-century under RCP2.6. The decrease in surface ocean pH is in the range of 0.06 to 0.07 (15 to 17% increase in acidity) for RCP2.6, 0.14 to 0.15 (38 to 41%) for RCP4.5, 0.20 to 0.21 (58 to 62%) for RCP6.0 and 0.30 to 0.32 (100 to 109%) for RCP8.5. *{2.2.4, Figure 2.1}*

Year-round reductions in Arctic sea ice are projected for all RCP scenarios. A nearly ice-free[11] Arctic Ocean in the summer sea-ice minimum in September before mid-century is *likely* for RCP8.5[12] (*medium confidence*). *{2.2.3, Figure 2.1}*

It is *virtually certain* that near-surface permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases, with the area of permafrost near the surface (upper 3.5 m) projected to decrease by 37% (RCP2.6) to 81% (RCP8.5) for the multi-model average (*medium confidence*). *{2.2.3}*

The global glacier volume, excluding glaciers on the periphery of Antarctica (and excluding the Greenland and Antarctic ice sheets), is projected to decrease by 15 to 55% for RCP2.6 and by 35 to 85% for RCP8.5 (*medium confidence*). *{2.2.3}*

[11] When sea-ice extent is less than one million km^2 for at least five consecutive years.

[12] Based on an assessment of the subset of models that most closely reproduce the climatological mean state and 1979–2012 trend of the Arctic sea-ice extent.

There has been significant improvement in understanding and projection of sea level change since the AR4. Global mean sea level rise will continue during the 21st century, *very likely* at a faster rate than observed from 1971 to 2010. For the period 2081–2100 relative to 1986–2005, the rise will *likely* be in the ranges of 0.26 to 0.55 m for RCP2.6, and of 0.45 to 0.82 m for RCP8.5 (*medium confidence*)[10] (Figure SPM.6b). Sea level rise will not be uniform across regions. By the end of the 21st century, it is *very likely* that sea level will rise in more than about 95% of the ocean area. About 70% of the coastlines worldwide are projected to experience a sea level change within ±20% of the global mean. *{2.2.3}*

SPM 2.3 Future risks and impacts caused by a changing climate

Climate change will amplify existing risks and create new risks for natural and human systems. Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development. *{2.3}*

Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems, including their ability to adapt. Rising rates and magnitudes of warming and other changes in the climate system, accompanied by ocean acidification, increase the risk of severe, pervasive and in some cases irreversible detrimental impacts. Some risks are particularly relevant for individual regions (Figure SPM.8), while others are global. The overall risks of future climate change impacts can be reduced by limiting the rate and magnitude of climate change, including ocean acidification. The precise levels of climate change sufficient to trigger abrupt and irreversible change remain uncertain, but the risk associated with crossing such thresholds increases with rising temperature (*medium confidence*). For risk assessment, it is important to evaluate the widest possible range of impacts, including low-probability outcomes with large consequences. *{1.5, 2.3, 2.4, 3.3, Box Introduction.1, Box 2.3, Box 2.4}*

A large fraction of species faces increased extinction risk due to climate change during and beyond the 21st century, especially as climate change interacts with other stressors (*high confidence*). Most plant species cannot naturally shift their geographical ranges sufficiently fast to keep up with current and high projected rates of climate change in most landscapes; most small mammals and freshwater molluscs will not be able to keep up at the rates projected under RCP4.5 and above in flat landscapes in this century (*high confidence*). Future risk is indicated to be high by the observation that natural global climate change at rates lower than current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years. Marine organisms will face progressively lower oxygen levels and high rates and magnitudes of ocean acidification (*high confidence*), with associated risks exacerbated by rising ocean temperature extremes (*medium confidence*). Coral reefs and polar ecosystems are highly vulnerable. Coastal systems and low-lying areas are at risk from sea level rise, which will continue for centuries even if the global mean temperature is stabilized (*high confidence*). *{2.3, 2.4, Figure 2.5}*

Climate change is projected to undermine food security (Figure SPM.9). Due to projected climate change by the mid-21st century and beyond, global marine species redistribution and marine biodiversity reduction in sensitive regions will challenge the sustained provision of fisheries productivity and other ecosystem services (*high confidence*). For wheat, rice and maize in tropical and temperate regions, climate change without adaptation is projected to negatively impact production for local temperature increases of 2°C or more above late 20th century levels, although individual locations may benefit (*medium confidence*). Global temperature increases of ~4°C or more[13] above late 20th century levels, combined with increasing food demand, would pose large risks to food security globally (*high confidence*). Climate change is projected to reduce renewable surface water and groundwater resources in most dry subtropical regions (*robust evidence*, *high agreement*), intensifying competition for water among sectors (*limited evidence*, *medium agreement*). *{2.3.1, 2.3.2}*

[13] Projected warming averaged over land is larger than global average warming for all RCP scenarios for the period 2081–2100 relative to 1986–2005. For regional projections, see Figure SPM.7. *{2.2}*

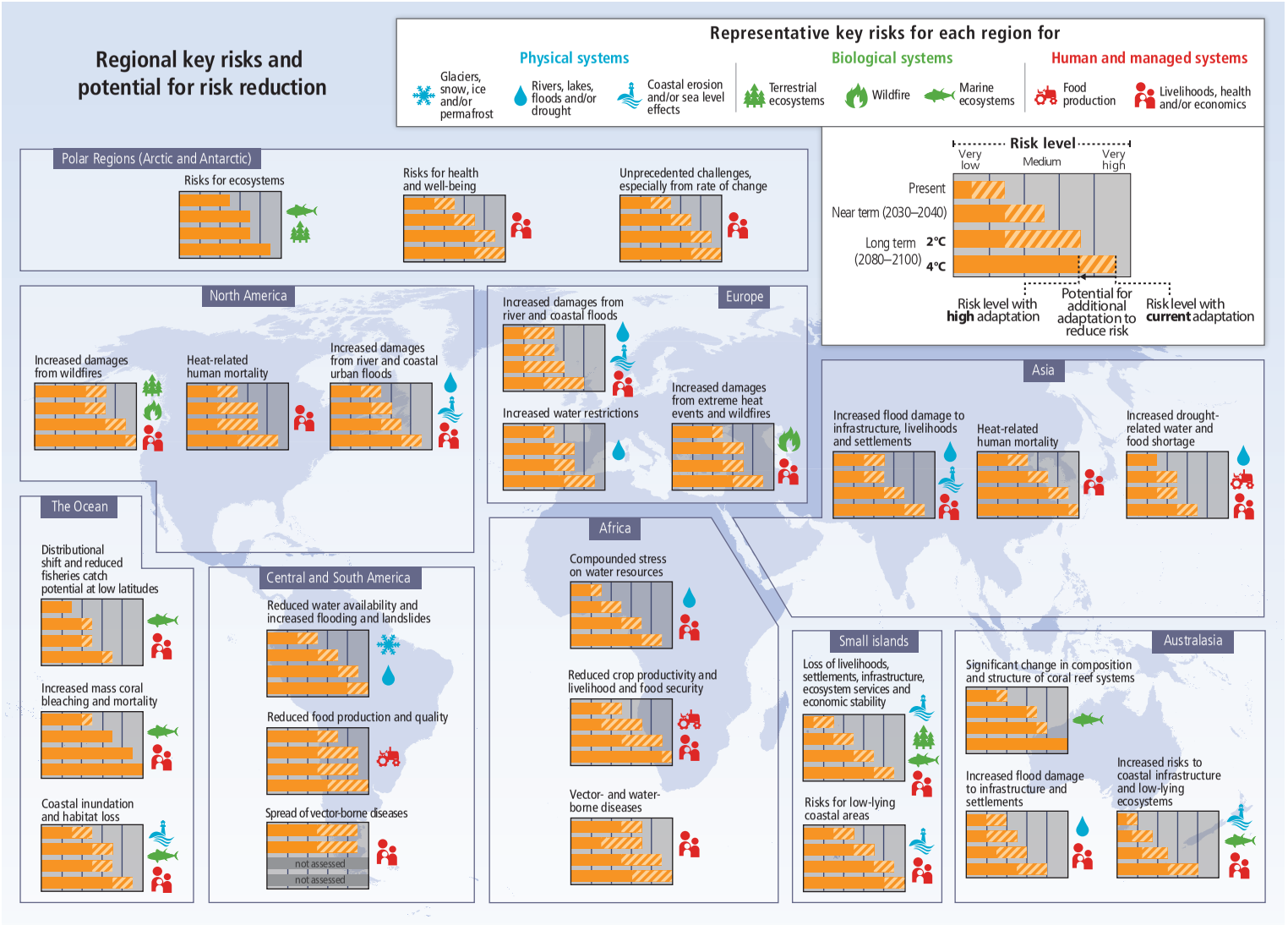


Figure SPM.8 | Representative key risks[14] for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation. Each key risk is assessed as very low, low, medium, high or very high. Risk levels are presented for three time frames: present, near term (here, for 2030–2040) and long term (here, for 2080–2100). In the near term, projected levels of global mean temperature increase do not diverge substantially across different emission scenarios. For the long term, risk levels are presented for two possible futures (2°C and 4°C global mean temperature increase above pre-industrial levels). For each timeframe, risk levels are indicated for a continuation of current adaptation and assuming high levels of current or future adaptation. Risk levels are not necessarily comparable, especially across regions. *{Figure 2.4}*

[14] Identification of key risks was based on expert judgment using the following specific criteria: large magnitude, high probability or irreversibility of impacts; timing of impacts; persistent vulnerability or exposure contributing to risks; or limited potential to reduce risks through adaptation or mitigation.

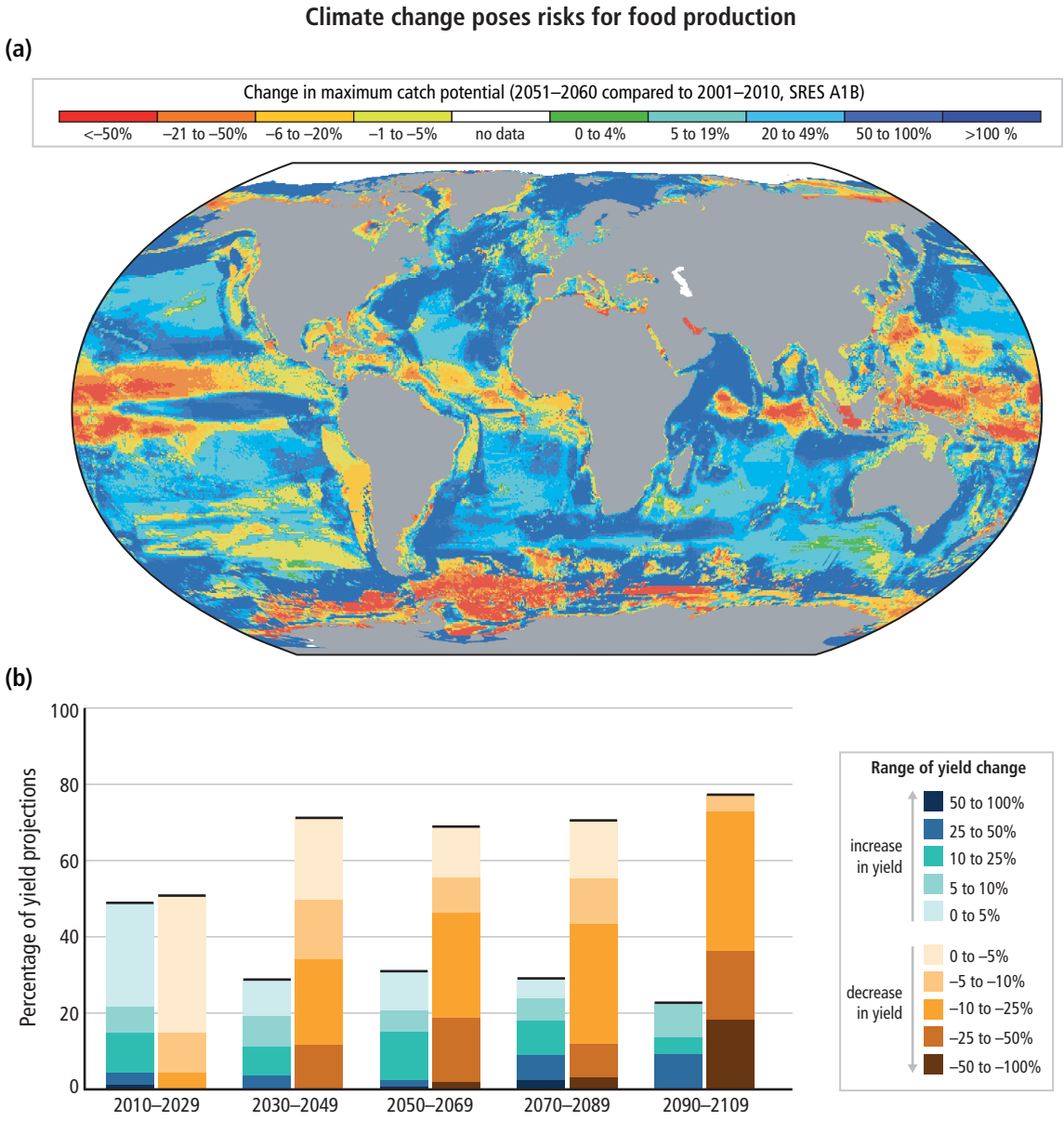


Figure SPM.9 | **(a)** Projected global redistribution of maximum catch potential of ~1000 exploited marine fish and invertebrate species. Projections compare the 10-year averages 2001–2010 and 2051–2060 using ocean conditions based on a single climate model under a moderate to high warming scenario, without analysis of potential impacts of overfishing or ocean acidification. **(b)** Summary of projected changes in crop yields (mostly wheat, maize, rice and soy), due to climate change over the 21st century. Data for each timeframe sum to 100%, indicating the percentage of projections showing yield increases versus decreases. The figure includes projections (based on 1090 data points) for different emission scenarios, for tropical and temperate regions and for adaptation and no-adaptation cases combined. Changes in crop yields are relative to late 20th century levels. *{Figure 2.6a, Figure 2.7}*

Until mid-century, projected climate change will impact human health mainly by exacerbating health problems that already exist (*very high confidence*). Throughout the 21st century, climate change is expected to lead to increases in ill-health in many regions and especially in developing countries with low income, as compared to a baseline without climate change (*high confidence*). By 2100 for RCP8.5, the combination of high temperature and humidity in some areas for parts of the year is expected to compromise common human activities, including growing food and working outdoors (*high confidence*). *{2.3.2}*

In urban areas climate change is projected to increase risks for people, assets, economies and ecosystems, including risks from heat stress, storms and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea level rise and storm surges (*very high confidence*). These risks are amplified for those lacking essential infrastructure and services or living in exposed areas. *{2.3.2}*

Rural areas are expected to experience major impacts on water availability and supply, food security, infrastructure and agricultural incomes, including shifts in the production areas of food and non-food crops around the world (*high confidence*). *{2.3.2}*

Aggregate economic losses accelerate with increasing temperature (*limited evidence, high agreement*), but global economic impacts from climate change are currently difficult to estimate. From a poverty perspective, climate change impacts are projected to slow down economic growth, make poverty reduction more difficult, further erode food security and prolong existing and create new poverty traps, the latter particularly in urban areas and emerging hotspots of hunger (*medium confidence*). International dimensions such as trade and relations among states are also important for understanding the risks of climate change at regional scales. *{2.3.2}*

Climate change is projected to increase displacement of people (*medium evidence, high agreement*). Populations that lack the resources for planned migration experience higher exposure to extreme weather events, particularly in developing countries with low income. Climate change can indirectly increase risks of violent conflicts by amplifying well-documented drivers of these conflicts such as poverty and economic shocks (*medium confidence*). *{2.3.2}*

SPM 2.4 Climate change beyond 2100, irreversibility and abrupt changes

Many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. The risks of abrupt or irreversible changes increase as the magnitude of the warming increases. *{2.4}*

Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions. A large fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial timescale, except in the case of a large net removal of CO_2 from the atmosphere over a sustained period. *{2.4, Figure 2.8}*

Stabilization of global average surface temperature does not imply stabilization for all aspects of the climate system. Shifting biomes, soil carbon, ice sheets, ocean temperatures and associated sea level rise all have their own intrinsic long timescales which will result in changes lasting hundreds to thousands of years after global surface temperature is stabilized. *{2.1, 2.4}*

There is *high confidence* that ocean acidification will increase for centuries if CO_2 emissions continue, and will strongly affect marine ecosystems. *{2.4}*

It is *virtually certain* that global mean sea level rise will continue for many centuries beyond 2100, with the amount of rise dependent on future emissions. The threshold for the loss of the Greenland ice sheet over a millennium or more, and an associated sea level rise of up to 7 m, is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) of global warming with respect to pre-industrial temperatures. Abrupt and irreversible ice loss from the Antarctic ice sheet is possible, but current evidence and understanding is insufficient to make a quantitative assessment. *{2.4}*

Magnitudes and rates of climate change associated with medium- to high-emission scenarios pose an increased risk of abrupt and irreversible regional-scale change in the composition, structure and function of marine, terrestrial and freshwater ecosystems, including wetlands (*medium confidence*). A reduction in permafrost extent is *virtually certain* with continued rise in global temperatures. *{2.4}*

SPM 3. Future Pathways for Adaptation, Mitigation and Sustainable Development

Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to climate-resilient pathways for sustainable development. *{3.2, 3.3, 3.4}*

SPM 3.1 Foundations of decision-making about climate change

Effective decision-making to limit climate change and its effects can be informed by a wide range of analytical approaches for evaluating expected risks and benefits, recognizing the importance of governance, ethical dimensions, equity, value judgments, economic assessments and diverse perceptions and responses to risk and uncertainty. *{3.1}*

Sustainable development and equity provide a basis for assessing climate policies. Limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication. Countries' past and future contributions to the accumulation of GHGs in the atmosphere are different, and countries also face varying challenges and circumstances and have different capacities to address mitigation and adaptation. Mitigation and adaptation raise issues of equity, justice and fairness. Many of those most vulnerable to climate change have contributed and contribute little to GHG emissions. Delaying mitigation shifts burdens from the present to the future, and insufficient adaptation responses to emerging impacts are already eroding the basis for sustainable development. Comprehensive strategies in response to climate change that are consistent with sustainable development take into account the co-benefits, adverse side effects and risks that may arise from both adaptation and mitigation options. *{3.1, 3.5, Box 3.4}*

The design of climate policy is influenced by how individuals and organizations perceive risks and uncertainties and take them into account. Methods of valuation from economic, social and ethical analysis are available to assist decision-making. These methods can take account of a wide range of possible impacts, including low-probability outcomes with large consequences. But they cannot identify a single best balance between mitigation, adaptation and residual climate impacts. *{3.1}*

Climate change has the characteristics of a collective action problem at the global scale, because most GHGs accumulate over time and mix globally, and emissions by any agent (e.g., individual, community, company, country) affect other agents. Effective mitigation will not be achieved if individual agents advance their own interests independently. Cooperative responses, including international cooperation, are therefore required to effectively mitigate GHG emissions and address other climate change issues. The effectiveness of adaptation can be enhanced through complementary actions across levels, including international cooperation. The evidence suggests that outcomes seen as equitable can lead to more effective cooperation. *{3.1}*

SPM 3.2 Climate change risks reduced by mitigation and adaptation

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*). Mitigation involves some level of co-benefits and of risks due to adverse side effects, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change, increasing the benefits from near-term mitigation efforts. *{3.2, 3.4}*

Mitigation and adaptation are complementary approaches for reducing risks of climate change impacts over different timescales (*high confidence*). Mitigation, in the near term and through the century, can substantially reduce climate change

impacts in the latter decades of the 21st century and beyond. Benefits from adaptation can already be realized in addressing current risks, and can be realized in the future for addressing emerging risks. *{3.2, 4.5}*

Five Reasons For Concern (RFCs) aggregate climate change risks and illustrate the implications of warming and of adaptation limits for people, economies and ecosystems across sectors and regions. The five RFCs are associated with: (1) Unique and threatened systems, (2) Extreme weather events, (3) Distribution of impacts, (4) Global aggregate impacts, and (5) Large-scale singular events. In this report, the RFCs provide information relevant to Article 2 of UNFCCC. *{Box 2.4}*

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*) (Figure SPM.10). In most scenarios without additional mitigation efforts (those with 2100 atmospheric concentrations

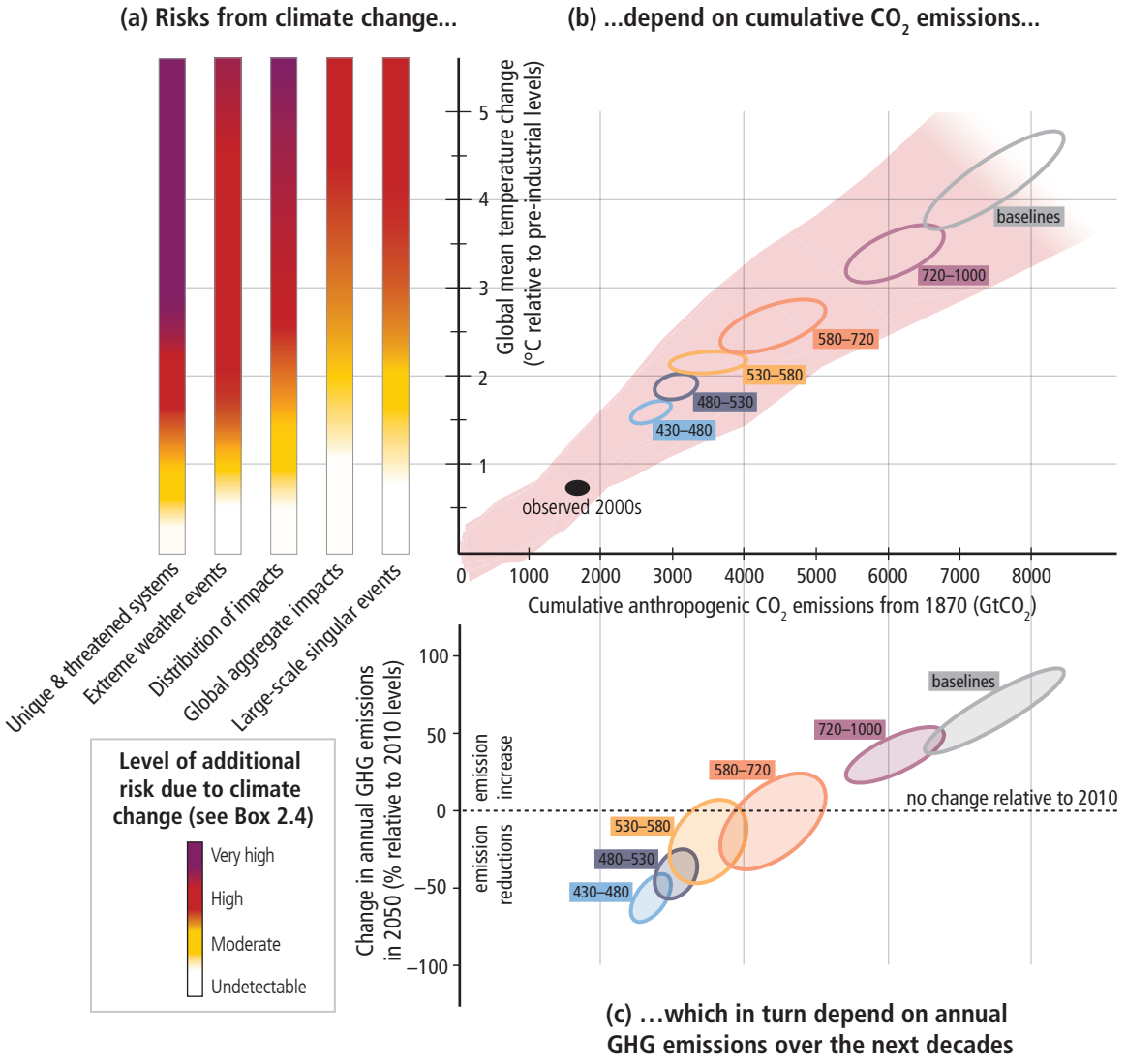


Figure SPM.10 | The relationship between risks from climate change, temperature change, cumulative carbon dioxide (CO_2) emissions and changes in annual greenhouse gas (GHG) emissions by 2050. Limiting risks across Reasons For Concern **(a)** would imply a limit for cumulative emissions of CO_2 **(b)** which would constrain annual GHG emissions over the next few decades **(c)**. **Panel a** reproduces the five Reasons For Concern *{Box 2.4}*. **Panel b** links temperature changes to cumulative CO_2 emissions (in $GtCO_2$) from 1870. They are based on Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations (pink plume) and on a simple climate model (median climate response in 2100), for the baselines and five mitigation scenario categories (six ellipses). Details are provided in Figure SPM.5. **Panel c** shows the relationship between the cumulative CO_2 emissions (in $GtCO_2$) of the scenario categories and their associated change in annual GHG emissions by 2050, expressed in percentage change (in percent $GtCO_2$-eq per year) relative to 2010. The ellipses correspond to the same scenario categories as in Panel b, and are built with a similar method (see details in Figure SPM.5). *{Figure 3.1}*

>1000 ppm CO_2-eq), warming is *more likely than not* to exceed 4°C above pre-industrial levels by 2100 (Table SPM.1). The risks associated with temperatures at or above 4°C include substantial species extinction, global and regional food insecurity, consequential constraints on common human activities and limited potential for adaptation in some cases (*high confidence*). Some risks of climate change, such as risks to unique and threatened systems and risks associated with extreme weather events, are moderate to high at temperatures 1°C to 2°C above pre-industrial levels. *{2.3, Figure 2.5, 3.2, 3.4, Box 2.4, Table SPM.1}*

Substantial cuts in GHG emissions over the next few decades can substantially reduce risks of climate change by limiting warming in the second half of the 21st century and beyond. Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. Limiting risks across RFCs would imply a limit for cumulative emissions of CO_2. Such a limit would require that global net emissions of CO_2 eventually decrease to zero and would constrain annual emissions over the next few decades (Figure SPM.10) (*high confidence*). But some risks from climate damages are unavoidable, even with mitigation and adaptation. *{2.2.5, 3.2, 3.4}*

Mitigation involves some level of co-benefits and risks, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change. Inertia in the economic and climate system and the possibility of irreversible impacts from climate change increase the benefits from near-term mitigation efforts (*high confidence*). Delays in additional mitigation or constraints on technological options increase the longer-term mitigation costs to hold climate change risks at a given level (Table SPM.2). *{3.2, 3.4}*

SPM 3.3 Characteristics of adaptation pathways

Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, especially with greater magnitudes and rates of climate change. Taking a longer-term perspective, in the context of sustainable development, increases the likelihood that more immediate adaptation actions will also enhance future options and preparedness. *{3.3}*

Adaptation can contribute to the well-being of populations, the security of assets and the maintenance of ecosystem goods, functions and services now and in the future. Adaptation is place- and context-specific (*high confidence*). A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability (*high confidence*). Integration of adaptation into planning, including policy design, and decision-making can promote synergies with development and disaster risk reduction. Building adaptive capacity is crucial for effective selection and implementation of adaptation options (*robust evidence, high agreement*). *{3.3}*

Adaptation planning and implementation can be enhanced through complementary actions across levels, from individuals to governments (*high confidence*). National governments can coordinate adaptation efforts of local and sub-national governments, for example by protecting vulnerable groups, by supporting economic diversification and by providing information, policy and legal frameworks and financial support (*robust evidence*, *high agreement*). Local government and the private sector are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing (*medium evidence*, *high agreement*). *{3.3}*

Adaptation planning and implementation at all levels of governance are contingent on societal values, objectives and risk perceptions (*high confidence*). Recognition of diverse interests, circumstances, social-cultural contexts and expectations can benefit decision-making processes. Indigenous, local and traditional knowledge systems and practices, including indigenous peoples' holistic view of community and environment, are a major resource for adapting to climate change, but these have not been used consistently in existing adaptation efforts. Integrating such forms of knowledge with existing practices increases the effectiveness of adaptation. *{3.3}*

Constraints can interact to impede adaptation planning and implementation (*high confidence*). Common constraints on implementation arise from the following: limited financial and human resources; limited integration or coordination of governance; uncertainties about projected impacts; different perceptions of risks; competing values; absence of key adaptation leaders and advocates; and limited tools to monitor adaptation effectiveness. Another constraint includes insufficient research, monitoring, and observation and the finance to maintain them. *{3.3}*

Greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*). Limits to adaptation emerge from the interaction among climate change and biophysical and/or socio-economic constraints. Further, poor planning or implementation, overemphasizing short-term outcomes or failing to sufficiently anticipate consequences can result in maladaptation, increasing the vulnerability or exposure of the target group in the future or the vulnerability of other people, places or sectors (*medium evidence, high agreement*). Underestimating the complexity of adaptation as a social process can create unrealistic expectations about achieving intended adaptation outcomes. *{3.3}*

Significant co-benefits, synergies and trade-offs exist between mitigation and adaptation and among different adaptation responses; interactions occur both within and across regions (*very high confidence*). Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, particularly at the intersections among water, energy, land use and biodiversity, but tools to understand and manage these interactions remain limited. Examples of actions with co-benefits include (i) improved energy efficiency and cleaner energy sources, leading to reduced emissions of health-damaging, climate-altering air pollutants; (ii) reduced energy and water consumption in urban areas through greening cities and recycling water; (iii) sustainable agriculture and forestry; and (iv) protection of ecosystems for carbon storage and other ecosystem services. *{3.3}*

Transformations in economic, social, technological and political decisions and actions can enhance adaptation and promote sustainable development (*high confidence*). At the national level, transformation is considered most effective when it reflects a country's own visions and approaches to achieving sustainable development in accordance with its national circumstances and priorities. Restricting adaptation responses to incremental changes to existing systems and structures, without considering transformational change, may increase costs and losses and miss opportunities. Planning and implementation of transformational adaptation could reflect strengthened, altered or aligned paradigms and may place new and increased demands on governance structures to reconcile different goals and visions for the future and to address possible equity and ethical implications. Adaptation pathways are enhanced by iterative learning, deliberative processes and innovation. *{3.3}*

SPM 3.4 Characteristics of mitigation pathways

There are multiple mitigation pathways that are *likely* to limit warming to below 2°C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of CO_2 and other long-lived greenhouse gases by the end of the century. Implementing such reductions poses substantial technological, economic, social and institutional challenges, which increase with delays in additional mitigation and if key technologies are not available. Limiting warming to lower or higher levels involves similar challenges but on different timescales. *{3.4}*

Without additional efforts to reduce GHG emissions beyond those in place today, global emissions growth is expected to persist, driven by growth in global population and economic activities. Global mean surface temperature increases in 2100 in baseline scenarios—those without additional mitigation—range from 3.7°C to 4.8°C above the average for 1850–1900 for a median climate response. They range from 2.5°C to 7.8°C when including climate uncertainty (5th to 95th percentile range) (*high confidence*). *{3.4}*

Emissions scenarios leading to CO_2-equivalent concentrations in 2100 of about 450 ppm or lower are *likely* to maintain warming below 2°C over the 21st century relative to pre-industrial levels[15]. These scenarios are characterized by 40 to 70% global anthropogenic GHG emissions reductions by 2050 compared to 2010[16], and emissions levels near zero or below in 2100. Mitigation scenarios reaching concentration levels of about 500 ppm CO_2-eq by 2100 are *more likely than not* to limit temperature change to less than 2°C, unless they temporarily overshoot concentration levels of roughly 530 ppm CO_2-eq

[15] For comparison, the CO_2-eq concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 to 520 ppm)

[16] This range differs from the range provided for a similar concentration category in the AR4 (50 to 85% lower than 2000 for CO_2 only). Reasons for this difference include that this report has assessed a substantially larger number of scenarios than in the AR4 and looks at all GHGs. In addition, a large proportion of the new scenarios include Carbon Dioxide Removal (CDR) technologies (see below). Other factors include the use of 2100 concentration levels instead of stabilization levels and the shift in reference year from 2000 to 2010.

before 2100, in which case they are *about as likely as not* to achieve that goal. In these 500 ppm CO_2-eq scenarios, global 2050 emissions levels are 25 to 55% lower than in 2010. Scenarios with higher emissions in 2050 are characterized by a greater reliance on Carbon Dioxide Removal (CDR) technologies beyond mid-century (and vice versa). Trajectories that are *likely* to limit warming to 3°C relative to pre-industrial levels reduce emissions less rapidly than those limiting warming to 2°C. A limited number of studies provide scenarios that are *more likely than not* to limit warming to 1.5°C by 2100; these scenarios are characterized by concentrations below 430 ppm CO_2-eq by 2100 and 2050 emission reduction between 70% and 95% below 2010. For a comprehensive overview of the characteristics of emissions scenarios, their CO_2-equivalent concentrations and their likelihood to keep warming to below a range of temperature levels, see Figure SPM.11 and Table SPM.1. *{3.4}*

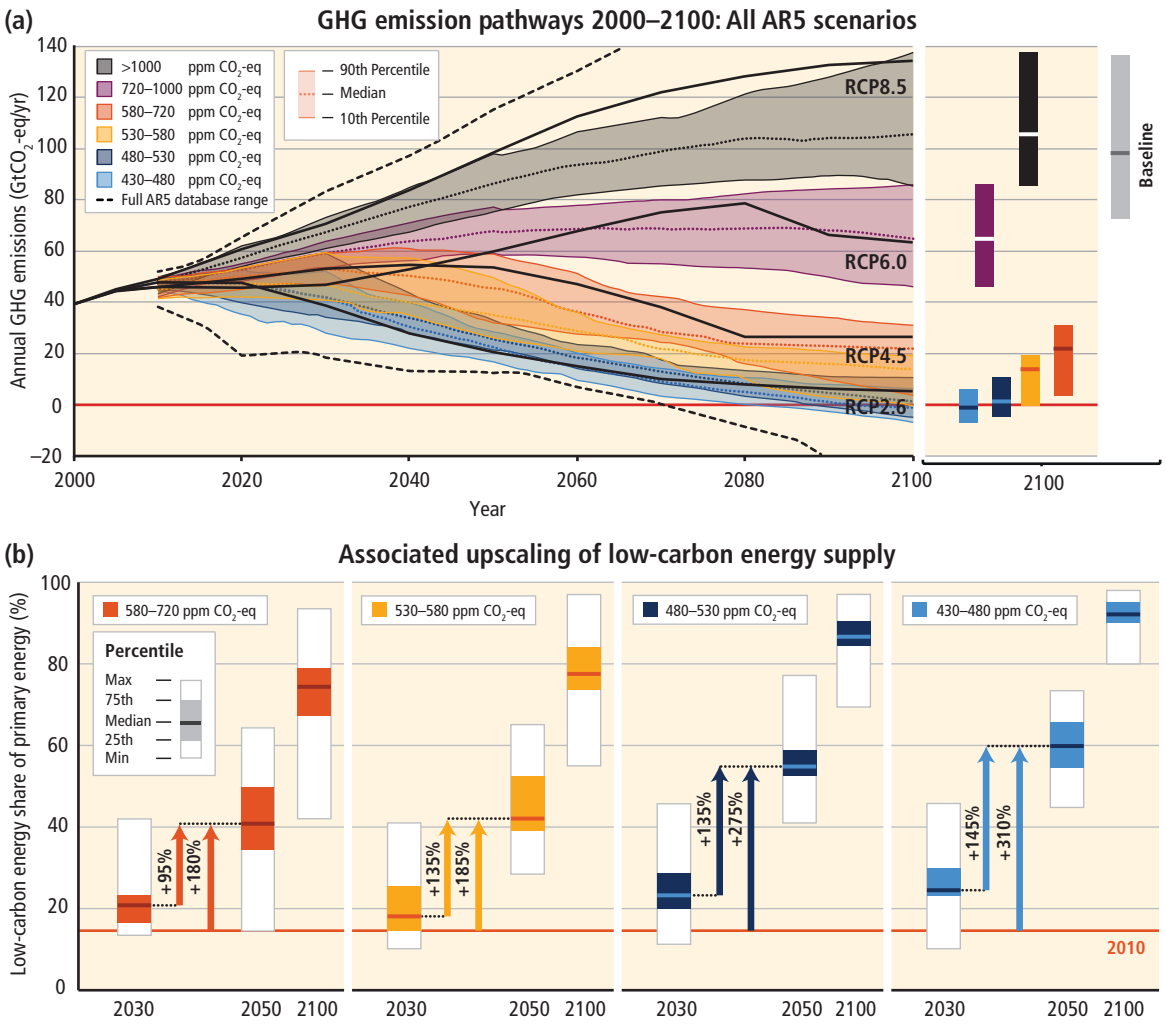


Figure SPM.11 | Global greenhouse gas emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) in baseline and mitigation scenarios for different long-term concentration levels **(a)** and associated upscaling requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100 compared to 2010 levels in mitigation scenarios **(b)**. *{Figure 3.2}*

Table SPM.1 | Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters the 10th to 90th percentile of the scenarios is shown [a]. *{Table 3.1}*

CO_2-eq Concentrations in 2100 (ppm CO_2-eq) [f] Category label (conc. range)	Subcategories	Relative position of the RCPs [d]	Change in CO_2-eq emissions compared to 2010 (in %) [c]		Likelihood of staying below a specific temperature level over the 21st century (relative to 1850–1900) [d, e]			
			2050	2100	1.5°C	2°C	3°C	4°C
<430	Only a limited number of individual model studies have explored levels below 430 ppm CO_2-eq [j]							
450 (430 to 480)	Total range [a, g]	RCP2.6	–72 to –41	–118 to –78	*More unlikely than likely*	*Likely*	*Likely*	*Likely*
500 (480 to 530)	No overshoot of 530 ppm CO_2-eq		–57 to –42	–107 to –73	*Unlikely*	*More likely than not*		
	Overshoot of 530 ppm CO_2-eq		–55 to –25	–114 to –90		*About as likely as not*		
550 (530 to 580)	No overshoot of 580 ppm CO_2-eq		–47 to –19	–81 to –59		*More unlikely than likely* [i]		
	Overshoot of 580 ppm CO_2-eq		–16 to 7	–183 to –86				
(580 to 650)	Total range	RCP4.5	–38 to 24	–134 to –50				
(650 to 720)	Total range		–11 to 17	–54 to –21		*Unlikely*	*More likely than not*	
(720 to 1000) [b]	Total range	RCP6.0	18 to 54	–7 to 72	*Unlikely* [h]		*More unlikely than likely*	
>1000 [b]	Total range	RCP8.5	52 to 95	74 to 178		*Unlikely* [h]	*Unlikely*	*More unlikely than likely*

Notes:

[a] The 'total range' for the 430 to 480 ppm CO_2-eq concentrations scenarios corresponds to the range of the 10th to 90th percentile of the subcategory of these scenarios shown in Table 6.3 of the Working Group III Report.

[b] Baseline scenarios fall into the >1000 and 720 to 1000 ppm CO_2-eq categories. The latter category also includes mitigation scenarios. The baseline scenarios in the latter category reach a temperature change of 2.5°C to 5.8°C above the average for 1850–1900 in 2100. Together with the baseline scenarios in the >1000 ppm CO_2-eq category, this leads to an overall 2100 temperature range of 2.5°C to 7.8°C (range based on median climate response: 3.7°C to 4.8°C) for baseline scenarios across both concentration categories.

[c] The global 2010 emissions are 31% above the 1990 emissions (consistent with the historic greenhouse gas emission estimates presented in this report). CO_2-eq emissions include the basket of Kyoto gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) as well as fluorinated gases).

[d] The assessment here involves a large number of scenarios published in the scientific literature and is thus not limited to the Representative Concentration Pathways (RCPs). To evaluate the CO_2-eq concentration and climate implications of these scenarios, the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) was used in a probabilistic mode. For a comparison between MAGICC model results and the outcomes of the models used in WGI, see WGI 12.4.1.2, 12.4.8 and WGIII 6.3.2.6.

[e] The assessment in this table is based on the probabilities calculated for the full ensemble of scenarios in WGIII AR5 using MAGICC and the assessment in WGI of the uncertainty of the temperature projections not covered by climate models. The statements are therefore consistent with the statements in WGI, which are based on the Coupled Model Intercomparison Project Phase 5 (CMIP5) runs of the RCPs and the assessed uncertainties. Hence, the likelihood statements reflect different lines of evidence from both WGs. This WGI method was also applied for scenarios with intermediate concentration levels where no CMIP5 runs are available. The likelihood statements are indicative only *{WGIII 6.3}* and follow broadly the terms used by the WGI SPM for temperature projections: likely 66–100%, more likely than not >50–100%, about as likely as not 33–66%, and unlikely 0–33%. In addition the term more unlikely than likely 0–<50% is used.

[f] The CO_2-equivalent concentration (see Glossary) is calculated on the basis of the total forcing from a simple carbon cycle/climate model, MAGICC. The CO_2-equivalent concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 to 520 ppm). This is based on the assessment of total anthropogenic radiative forcing for 2011 relative to 1750 in WGI, i.e., 2.3 W/m^2, uncertainty range 1.1 to 3.3 W/m^2.

[g] The vast majority of scenarios in this category overshoot the category boundary of 480 ppm CO_2-eq concentration.

[h] For scenarios in this category, no CMIP5 run or MAGICC realization stays below the respective temperature level. Still, an *unlikely* assignment is given to reflect uncertainties that may not be reflected by the current climate models.

[i] Scenarios in the 580 to 650 ppm CO_2-eq category include both overshoot scenarios and scenarios that do not exceed the concentration level at the high end of the category (e.g., RCP4.5). The latter type of scenarios, in general, have an assessed probability of *more unlikely than likely* to stay below the 2°C temperature level, while the former are mostly assessed to have an *unlikely* probability of staying below this level.

[j] In these scenarios, global CO_2-eq emissions in 2050 are between 70 to 95% below 2010 emissions, and they are between 110 to 120% below 2010 emissions in 2100.

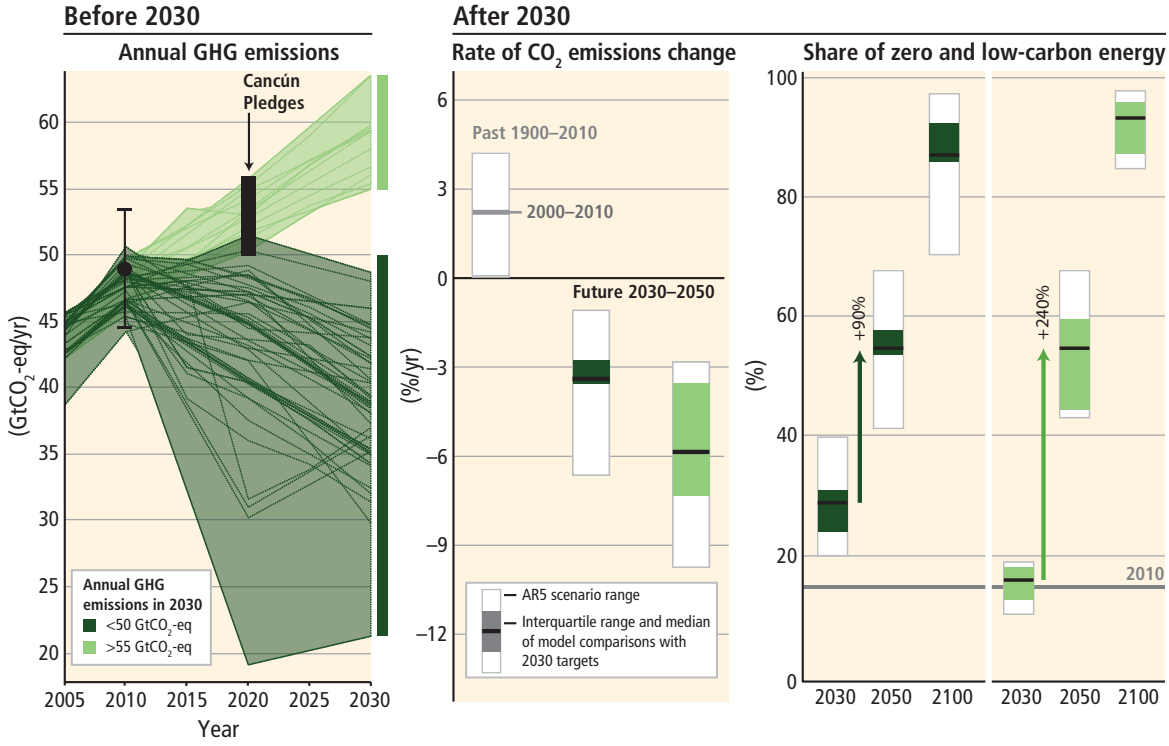


Figure SPM.12 | The implications of different 2030 greenhouse gas (GHG) emissions levels for the rate of carbon dioxide (CO_2) emissions reductions and low-carbon energy upscaling in mitigation scenarios that are at least *about as likely as not* to keep warming throughout the 21st century below 2°C relative to pre-industrial levels (2100 CO_2-equivalent concentrations of 430 to 530 ppm). The scenarios are grouped according to different emissions levels by 2030 (coloured in different shades of green). The left panel shows the pathways of GHG emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) leading to these 2030 levels. The black dot with whiskers gives historic GHG emission levels and associated uncertainties in 2010 as reported in Figure SPM.2. The black bar shows the estimated uncertainty range of GHG emissions implied by the Cancún Pledges. The middle panel denotes the average annual CO_2 emissions reduction rates for the period 2030–2050. It compares the median and interquartile range across scenarios from recent inter-model comparisons with explicit 2030 interim goals to the range of scenarios in the Scenario Database for WGIII AR5. Annual rates of historical emissions change (sustained over a period of 20 years) and the average annual CO_2 emission change between 2000 and 2010 are shown as well. The arrows in the right panel show the magnitude of zero and low-carbon energy supply upscaling from 2030 to 2050 subject to different 2030 GHG emissions levels. Zero- and low-carbon energy supply includes renewables, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS) or bioenergy with CCS (BECCS). [Note: Only scenarios that apply the full, unconstrained mitigation technology portfolio of the underlying models (default technology assumption) are shown. Scenarios with large net negative global emissions (>20 $GtCO_2$-eq/yr), scenarios with exogenous carbon price assumptions and scenarios with 2010 emissions significantly outside the historical range are excluded.] *{Figure 3.3}*

Mitigation scenarios reaching about 450 ppm CO_2-eq in 2100 (consistent with a *likely* chance to keep warming below 2°C relative to pre-industrial levels) typically involve temporary overshoot[17] of atmospheric concentrations, as do many scenarios reaching about 500 ppm CO_2-eq to about 550 ppm CO_2-eq in 2100 (Table SPM.1). Depending on the level of overshoot, overshoot scenarios typically rely on the availability and widespread deployment of bioenergy with carbon dioxide capture and storage (BECCS) and afforestation in the second half of the century. The availability and scale of these and other CDR technologies and methods are uncertain and CDR technologies are, to varying degrees, associated with challenges and risks[18]. CDR is also prevalent in many scenarios without overshoot to compensate for residual emissions from sectors where mitigation is more expensive (*high confidence*). *{3.4, Box 3.3}*

Reducing emissions of non-CO_2 agents can be an important element of mitigation strategies. All current GHG emissions and other forcing agents affect the rate and magnitude of climate change over the next few decades, although long-term warming is mainly driven by CO_2 emissions. Emissions of non-CO_2 forcers are often expressed as 'CO_2-equivalent emissions', but the choice of metric to calculate these emissions, and the implications for the emphasis and timing of abatement of the various climate forcers, depends on application and policy context and contains value judgments. *{3.4, Box 3.2}*

[17] In concentration 'overshoot' scenarios, concentrations peak during the century and then decline.

[18] CDR methods have biogeochemical and technological limitations to their potential on the global scale. There is insufficient knowledge to quantify how much CO_2 emissions could be partially offset by CDR on a century timescale. CDR methods may carry side effects and long-term consequences on a global scale.

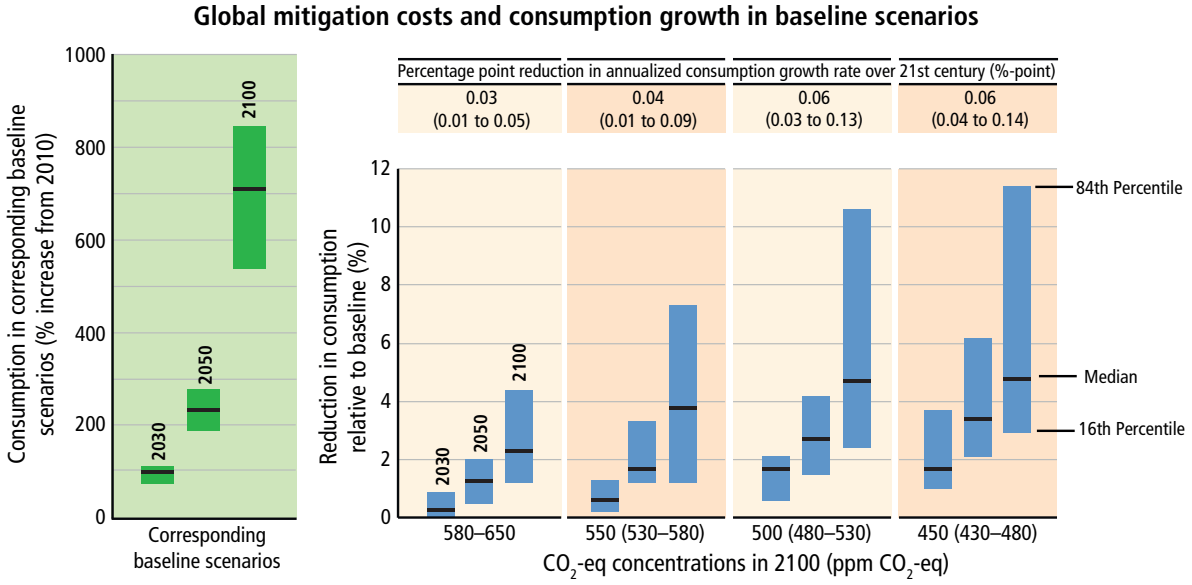


Figure SPM.13 | Global mitigation costs in cost-effective scenarios at different atmospheric concentrations levels in 2100. Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions. Consumption losses are shown relative to a baseline development without climate policy (left panel). The table at the top shows percentage points of annualized consumption growth reductions relative to consumption growth in the baseline of 1.6 to 3% per year (e.g., if the reduction is 0.06 percentage points per year due to mitigation, and baseline growth is 2.0% per year, then the growth rate with mitigation would be 1.94% per year). Cost estimates shown in this table do not consider the benefits of reduced climate change or co-benefits and adverse side effects of mitigation. Estimates at the high end of these cost ranges are from models that are relatively inflexible to achieve the deep emissions reductions required in the long run to meet these goals and/or include assumptions about market imperfections that would raise costs. *{Figure 3.4}*

Delaying additional mitigation to 2030 will substantially increase the challenges associated with limiting warming over the 21st century to below 2°C relative to pre-industrial levels. It will require substantially higher rates of emissions reductions from 2030 to 2050; a much more rapid scale-up of low-carbon energy over this period; a larger reliance on CDR in the long term; and higher transitional and long-term economic impacts. Estimated global emissions levels in 2020 based on the Cancún Pledges are not consistent with cost-effective mitigation trajectories that are at least *about as likely as not* to limit warming to below 2°C relative to pre-industrial levels, but they do not preclude the option to meet this goal (*high confidence*) (Figure SPM.12, Table SPM.2). *{3.4}*

Estimates of the aggregate economic costs of mitigation vary widely depending on methodologies and assumptions, but increase with the stringency of mitigation. Scenarios in which all countries of the world begin mitigation immediately, in which there is a single global carbon price, and in which all key technologies are available have been used as a cost-effective benchmark for estimating macro-economic mitigation costs (Figure SPM.13). Under these assumptions mitigation scenarios that are *likely* to limit warming to below 2°C through the 21st century relative to pre-industrial levels entail losses in global consumption—not including benefits of reduced climate change as well as co-benefits and adverse side effects of mitigation—of 1 to 4% (median: 1.7%) in 2030, 2 to 6% (median: 3.4%) in 2050 and 3 to 11% (median: 4.8%) in 2100 relative to consumption in baseline scenarios that grows anywhere from 300% to more than 900% over the century (Figure SPM.13). These numbers correspond to an annualized reduction of consumption growth by 0.04 to 0.14 (median: 0.06) percentage points over the century relative to annualized consumption growth in the baseline that is between 1.6 and 3% per year (*high confidence*). *{3.4}*

In the absence or under limited availability of mitigation technologies (such as bioenergy, CCS and their combination BECCS, nuclear, wind/solar), mitigation costs can increase substantially depending on the technology considered. Delaying additional mitigation increases mitigation costs in the medium to long term. Many models could not limit *likely* warming to below 2°C over the 21st century relative to pre-industrial levels if additional mitigation is considerably delayed. Many models could not limit *likely* warming to below 2°C if bioenergy, CCS and their combination (BECCS) are limited (*high confidence*) (Table SPM.2). *{3.4}*

Table SPM.2 | Increase in global mitigation costs due to either limited availability of specific technologies or delays in additional mitigation [a] relative to cost-effective scenarios [b]. The increase in costs is given for the median estimate and the 16th to 84th percentile range of the scenarios (in parentheses) [c]. In addition, the sample size of each scenario set is provided in the coloured symbols. The colours of the symbols indicate the fraction of models from systematic model comparison exercises that could successfully reach the targeted concentration level. *{Table 3.2}*

Mitigation cost increases in scenarios with limited availability of technologies [d] *[% increase in total discounted [e] mitigation costs (2015–2100) relative to default technology assumptions]*					**Mitigation cost increases due to delayed additional mitigation until 2030** *[% increase in mitigation costs relative to immediate mitigation]*	
2100 concentrations (ppm CO_2-eq)	no CCS	nuclear phase out	limited solar/wind	limited bioenergy	medium term costs (2030–2050)	long term costs (2050–2100)
450 (430 to 480)	138% (29 to 297%) 4	7% (4 to 18%) 8	6% (2 to 29%) 8	64% (44 to 78%) 8	44% (2 to 78%) 29	37% (16 to 82%) 29
500 (480 to 530)	not available (n.a.)	n.a.	n.a.	n.a.		
550 (530 to 580)	39% (18 to 78%) 11	13% (2 to 23%) 10	8% (5 to 15%) 10	18% (4 to 66%) 12	15% (3 to 32%)	16% (5 to 24%)
580 to 650	n.a.	n.a.	n.a.	n.a.		

Symbol legend—fraction of models successful in producing scenarios (numbers indicate the number of successful models)

: all models successful

: between 80 and 100% of models successful

: between 50 and 80% of models successful

: less than 50% of models successful

Notes:

[a] Delayed mitigation scenarios are associated with greenhouse gas emission of more than 55 $GtCO_2$-eq in 2030, and the increase in mitigation costs is measured relative to cost-effective mitigation scenarios for the same long-term concentration level.

[b] Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions.

[c] The range is determined by the central scenarios encompassing the 16th to 84th percentile range of the scenario set. Only scenarios with a time horizon until 2100 are included. Some models that are included in the cost ranges for concentration levels above 530 ppm CO_2-eq in 2100 could not produce associated scenarios for concentration levels below 530 ppm CO_2-eq in 2100 with assumptions about limited availability of technologies and/or delayed additional mitigation.

[d] No CCS: carbon dioxide capture and storage is not included in these scenarios. Nuclear phase out: no addition of nuclear power plants beyond those under construction, and operation of existing plants until the end of their lifetime. Limited Solar/Wind: a maximum of 20% global electricity generation from solar and wind power in any year of these scenarios. Limited Bioenergy: a maximum of 100 EJ/yr modern bioenergy supply globally (modern bioenergy used for heat, power, combinations and industry was around 18 EJ/yr in 2008). EJ = Exajoule = 10^{18} Joule.

[e] Percentage increase of net present value of consumption losses in percent of baseline consumption (for scenarios from general equilibrium models) and abatement costs in percent of baseline gross domestic product (GDP, for scenarios from partial equilibrium models) for the period 2015–2100, discounted at 5% per year.

Mitigation scenarios reaching about 450 or 500 ppm CO_2-eq by 2100 show reduced costs for achieving air quality and energy security objectives, with significant co-benefits for human health, ecosystem impacts and sufficiency of resources and resilience of the energy system. *{4.4.2.2}*

Mitigation policy could devalue fossil fuel assets and reduce revenues for fossil fuel exporters, but differences between regions and fuels exist (*high confidence*). Most mitigation scenarios are associated with reduced revenues from coal and oil trade for major exporters (*high confidence*). The availability of CCS would reduce the adverse effects of mitigation on the value of fossil fuel assets (*medium confidence*). *{4.4.2.2}*

Solar Radiation Management (SRM) involves large-scale methods that seek to reduce the amount of absorbed solar energy in the climate system. SRM is untested and is not included in any of the mitigation scenarios. If it were deployed, SRM would

entail numerous uncertainties, side effects, risks and shortcomings and has particular governance and ethical implications. SRM would not reduce ocean acidification. If it were terminated, there is *high confidence* that surface temperatures would rise very rapidly impacting ecosystems susceptible to rapid rates of change. *{Box 3.3}*

SPM 4. Adaptation and Mitigation

Many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives. *{4}*

SPM 4.1 Common enabling factors and constraints for adaptation and mitigation responses

Adaptation and mitigation responses are underpinned by common enabling factors. These include effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods and behavioural and lifestyle choices. *{4.1}*

Inertia in many aspects of the socio-economic system constrains adaptation and mitigation options (*medium evidence, high agreement*). Innovation and investments in environmentally sound infrastructure and technologies can reduce GHG emissions and enhance resilience to climate change (*very high confidence*). *{4.1}*

Vulnerability to climate change, GHG emissions and the capacity for adaptation and mitigation are strongly influenced by livelihoods, lifestyles, behaviour and culture (*medium evidence, medium agreement*). Also, the social acceptability and/or effectiveness of climate policies are influenced by the extent to which they incentivize or depend on regionally appropriate changes in lifestyles or behaviours. *{4.1}*

For many regions and sectors, enhanced capacities to mitigate and adapt are part of the foundation essential for managing climate change risks (*high confidence*). Improving institutions as well as coordination and cooperation in governance can help overcome regional constraints associated with mitigation, adaptation and disaster risk reduction (*very high confidence*). *{4.1}*

SPM 4.2 Response options for adaptation

Adaptation options exist in all sectors, but their context for implementation and potential to reduce climate-related risks differs across sectors and regions. Some adaptation responses involve significant co-benefits, synergies and trade-offs. Increasing climate change will increase challenges for many adaptation options. *{4.2}*

Adaptation experience is accumulating across regions in the public and private sectors and within communities. There is increasing recognition of the value of social (including local and indigenous), institutional, and ecosystem-based measures and of the extent of constraints to adaptation. Adaptation is becoming embedded in some planning processes, with more limited implementation of responses (*high confidence*). *{1.6, 4.2, 4.4.2.1}*

The need for adaptation along with associated challenges is expected to increase with climate change (*very high confidence*). Adaptation options exist in all sectors and regions, with diverse potential and approaches depending on their context in vulnerability reduction, disaster risk management or proactive adaptation planning (Table SPM.3). Effective strategies and actions consider the potential for co-benefits and opportunities within wider strategic goals and development plans. *{4.2}*

Table SPM.3 | Approaches for managing the risks of climate change through adaptation. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Examples are presented in no specific order and can be relevant to more than one category. *{Table 4.2}*

Overlapping Approaches	Category	Examples
Vulnerability & Exposure Reduction through development, planning & practices including many low-regrets measures; **Adaptation** including incremental & transformational adjustments; **Transformation**	Human development	Improved access to education, nutrition, health facilities, energy, safe housing & settlement structures, & social support structures; Reduced gender inequality & marginalization in other forms.
	Poverty alleviation	Improved access to & control of local resources; Land tenure; Disaster risk reduction; Social safety nets & social protection; Insurance schemes.
	Livelihood security	Income, asset & livelihood diversification; Improved infrastructure; Access to technology & decision-making fora; Increased decision-making power; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
	Disaster risk management	Early warning systems; Hazard & vulnerability mapping; Diversifying water resources; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements.
	Ecosystem management	Maintaining wetlands & urban green spaces; Coastal afforestation; Watershed & reservoir management; Reduction of other stressors on ecosystems & of habitat fragmentation; Maintenance of genetic diversity; Manipulation of disturbance regimes; Community-based natural resource management.
	Spatial or land-use planning	Provisioning of adequate housing, infrastructure & services; Managing development in flood prone & other high risk areas; Urban planning & upgrading programs; Land zoning laws; Easements; Protected areas.
	Structural/physical	***Engineered & built-environment options***: Sea walls & coastal protection structures; Flood levees; Water storage; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements; Floating houses; Power plant & electricity grid adjustments.
		Technological options: New crop & animal varieties; Indigenous, traditional & local knowledge, technologies & methods; Efficient irrigation; Water-saving technologies; Desalinisation; Conservation agriculture; Food storage & preservation facilities; Hazard & vulnerability mapping & monitoring; Early warning systems; Building insulation; Mechanical & passive cooling; Technology development, transfer & diffusion.
		Ecosystem-based options: Ecological restoration; Soil conservation; Afforestation & reforestation; Mangrove conservation & replanting; Green infrastructure (e.g., shade trees, green roofs); Controlling overfishing; Fisheries co-management; Assisted species migration & dispersal; Ecological corridors; Seed banks, gene banks & other *ex situ* conservation; Community-based natural resource management.
		Services: Social safety nets & social protection; Food banks & distribution of food surplus; Municipal services including water & sanitation; Vaccination programs; Essential public health services; Enhanced emergency medical services.
	Institutional	***Economic options***: Financial incentives; Insurance; Catastrophe bonds; Payments for ecosystem services; Pricing water to encourage universal provision and careful use; Microfinance; Disaster contingency funds; Cash transfers; Public-private partnerships.
		Laws & regulations: Land zoning laws; Building standards & practices; Easements; Water regulations & agreements; Laws to support disaster risk reduction; Laws to encourage insurance purchasing; Defined property rights & land tenure security; Protected areas; Fishing quotas; Patent pools & technology transfer.
		National & government policies & programs: National & regional adaptation plans including mainstreaming; Sub-national & local adaptation plans; Economic diversification; Urban upgrading programs; Municipal water management programs; Disaster planning & preparedness; Integrated water resource management; Integrated coastal zone management; Ecosystem-based management; Community-based adaptation.
	Social	***Educational options***: Awareness raising & integrating into education; Gender equity in education; Extension services; Sharing indigenous, traditional & local knowledge; Participatory action research & social learning; Knowledge-sharing & learning platforms.
		Informational options: Hazard & vulnerability mapping; Early warning & response systems; Systematic monitoring & remote sensing; Climate services; Use of indigenous climate observations; Participatory scenario development; Integrated assessments.
		Behavioural options: Household preparation & evacuation planning; Migration; Soil & water conservation; Storm drain clearance; Livelihood diversification; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
	Spheres of change	***Practical***: Social & technical innovations, behavioural shifts, or institutional & managerial changes that produce substantial shifts in outcomes.
		Political: Political, social, cultural & ecological decisions & actions consistent with reducing vulnerability & risk & supporting adaptation, mitigation & sustainable development.
		Personal: Individual & collective assumptions, beliefs, values & worldviews influencing climate-change responses.

SPM 4.3 Response options for mitigation

Mitigation options are available in every major sector. Mitigation can be more cost-effective if using an integrated approach that combines measures to reduce energy use and the greenhouse gas intensity of end-use sectors, decarbonize energy supply, reduce net emissions and enhance carbon sinks in land-based sectors. *{4.3}*

Well-designed systemic and cross-sectoral mitigation strategies are more cost-effective in cutting emissions than a focus on individual technologies and sectors, with efforts in one sector affecting the need for mitigation in others (*medium confidence*). Mitigation measures intersect with other societal goals, creating the possibility of co-benefits or adverse side effects. These intersections, if well-managed, can strengthen the basis for undertaking climate action. *{4.3}*

Emissions ranges for baseline scenarios and mitigation scenarios that limit CO_2-equivalent concentrations to low levels (about 450 ppm CO_2-eq, *likely* to limit warming to 2°C above pre-industrial levels) are shown for different sectors and gases in Figure SPM.14. Key measures to achieve such mitigation goals include decarbonizing (i.e., reducing the carbon intensity of) electricity generation (*medium evidence, high agreement*) as well as efficiency enhancements and behavioural changes, in order to reduce energy demand compared to baseline scenarios without compromising development (*robust evidence, high agreement*). In scenarios reaching 450 ppm CO_2-eq concentrations by 2100, global CO_2 emissions from the energy supply sector are projected to decline over the next decade and are characterized by reductions of 90% or more below 2010 levels between 2040 and 2070. In the majority of low-concentration stabilization scenarios (about 450 to about 500 ppm CO_2-eq, at least *about as likely as not* to limit warming to 2°C above pre-industrial levels), the share of low-carbon electricity supply (comprising renewable energy (RE), nuclear and carbon dioxide capture and storage (CCS) including bioenergy with carbon dioxide capture and storage (BECCS)) increases from the current share of approximately 30% to more than 80% by 2050, and fossil fuel power generation without CCS is phased out almost entirely by 2100. *{4.3}*

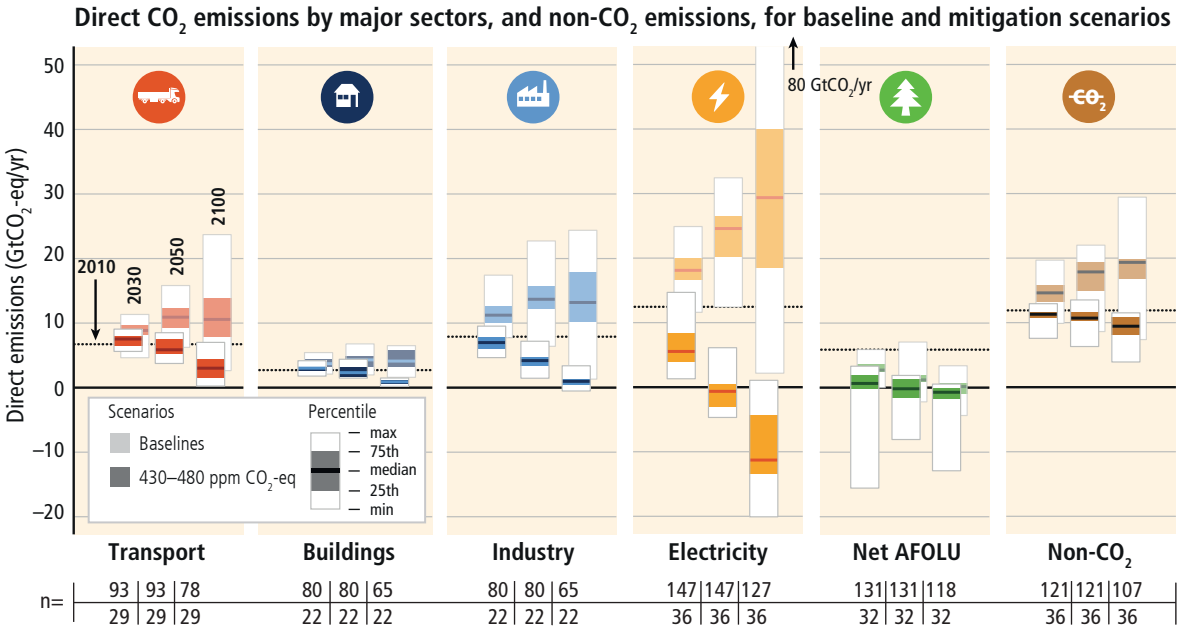


Figure SPM.14 | Carbon dioxide (CO_2) emissions by sector and total non-CO_2 greenhouse gases (Kyoto gases) across sectors in baseline (faded bars) and mitigation scenarios (solid colour bars) that reach about 450 (430 to 480) ppm CO_2-eq concentrations in 2100 (*likely* to limit warming to 2°C above pre-industrial levels). Mitigation in the end-use sectors leads also to indirect emissions reductions in the upstream energy supply sector. Direct emissions of the end-use sectors thus do not include the emission reduction potential at the supply-side due to, for example, reduced electricity demand. The numbers at the bottom of the graphs refer to the number of scenarios included in the range (upper row: baseline scenarios; lower row: mitigation scenarios), which differs across sectors and time due to different sectoral resolution and time horizon of models. Emissions ranges for mitigation scenarios include the full portfolio of mitigation options; many models cannot reach 450 ppm CO_2-eq concentration by 2100 in the absence of carbon dioxide capture and storage (CCS). Negative emissions in the electricity sector are due to the application of bioenergy with carbon dioxide capture and storage (BECCS). 'Net' agriculture, forestry and other land use (AFOLU) emissions consider afforestation, reforestation as well as deforestation activities. *{4.3, Figure 4.1}*

Near-term reductions in energy demand are an important element of cost-effective mitigation strategies, provide more flexibility for reducing carbon intensity in the energy supply sector, hedge against related supply-side risks, avoid lock-in to carbon-intensive infrastructures, and are associated with important co-benefits. The most cost-effective mitigation options in forestry are afforestation, sustainable forest management and reducing deforestation, with large differences in their relative importance across regions; and in agriculture, cropland management, grazing land management and restoration of organic soils (*medium evidence, high agreement*). *{4.3, Figures 4.1, 4.2, Table 4.3}*

Behaviour, lifestyle and culture have a considerable influence on energy use and associated emissions, with high mitigation potential in some sectors, in particular when complementing technological and structural change (*medium evidence, medium agreement*). Emissions can be substantially lowered through changes in consumption patterns, adoption of energy savings measures, dietary change and reduction in food wastes. *{4.1, 4.3}*

SPM 4.4 Policy approaches for adaptation and mitigation, technology and finance

Effective adaptation and mitigation responses will depend on policies and measures across multiple scales: international, regional, national and sub-national. Policies across all scales supporting technology development, diffusion and transfer, as well as finance for responses to climate change, can complement and enhance the effectiveness of policies that directly promote adaptation and mitigation. *{4.4}*

International cooperation is critical for effective mitigation, even though mitigation can also have local co-benefits. Adaptation focuses primarily on local to national scale outcomes, but its effectiveness can be enhanced through coordination across governance scales, including international cooperation: *{3.1, 4.4.1}*

- The United Nations Framework Convention on Climate Change (UNFCCC) is the main multilateral forum focused on addressing climate change, with nearly universal participation. Other institutions organized at different levels of governance have resulted in diversifying international climate change cooperation. *{4.4.1}*

- The Kyoto Protocol offers lessons towards achieving the ultimate objective of the UNFCCC, particularly with respect to participation, implementation, flexibility mechanisms and environmental effectiveness (*medium evidence, low agreement*). *{4.4.1}*

- Policy linkages among regional, national and sub-national climate policies offer potential climate change mitigation benefits (*medium evidence, medium agreement*). Potential advantages include lower mitigation costs, decreased emission leakage and increased market liquidity. *{4.4.1}*

- International cooperation for supporting adaptation planning and implementation has received less attention historically than mitigation but is increasing and has assisted in the creation of adaptation strategies, plans and actions at the national, sub-national and local level (*high confidence*). *{4.4.1}*

There has been a considerable increase in national and sub-national plans and strategies on both adaptation and mitigation since the AR4, with an increased focus on policies designed to integrate multiple objectives, increase co-benefits and reduce adverse side effects (*high confidence*): *{4.4.2.1, 4.4.2.2}*

- National governments play key roles in adaptation planning and implementation (*robust evidence, high agreement*) through coordinating actions and providing frameworks and support. While local government and the private sector have different functions, which vary regionally, they are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing (*medium evidence, high agreement*). *{4.4.2.1}*

- Institutional dimensions of adaptation governance, including the integration of adaptation into planning and decision-making, play a key role in promoting the transition from planning to implementation of adaptation (*robust evidence,*

high agreement). Examples of institutional approaches to adaptation involving multiple actors include economic options (e.g., insurance, public-private partnerships), laws and regulations (e.g., land-zoning laws) and national and government policies and programmes (e.g., economic diversification). *{4.2, 4.4.2.1, Table SPM.3}*

- In principle, mechanisms that set a carbon price, including cap and trade systems and carbon taxes, can achieve mitigation in a cost-effective way but have been implemented with diverse effects due in part to national circumstances as well as policy design. The short-run effects of cap and trade systems have been limited as a result of loose caps or caps that have not proved to be constraining (*limited evidence, medium agreement*). In some countries, tax-based policies specifically aimed at reducing GHG emissions—alongside technology and other policies—have helped to weaken the link between GHG emissions and GDP (*high confidence*). In addition, in a large group of countries, fuel taxes (although not necessarily designed for the purpose of mitigation) have had effects that are akin to sectoral carbon taxes. *{4.4.2.2}*

- Regulatory approaches and information measures are widely used and are often environmentally effective (*medium evidence, medium agreement*). Examples of regulatory approaches include energy efficiency standards; examples of information programmes include labelling programmes that can help consumers make better-informed decisions. *{4.4.2.2}*

- Sector-specific mitigation policies have been more widely used than economy-wide policies (*medium evidence, high agreement*). Sector-specific policies may be better suited to address sector-specific barriers or market failures and may be bundled in packages of complementary policies. Although theoretically more cost-effective, administrative and political barriers may make economy-wide policies harder to implement. Interactions between or among mitigation policies may be synergistic or may have no additive effect on reducing emissions. *{4.4.2.2}*

- Economic instruments in the form of subsidies may be applied across sectors, and include a variety of policy designs, such as tax rebates or exemptions, grants, loans and credit lines. An increasing number and variety of renewable energy (RE) policies including subsidies—motivated by many factors—have driven escalated growth of RE technologies in recent years. At the same time, reducing subsidies for GHG-related activities in various sectors can achieve emission reductions, depending on the social and economic context (*high confidence*). *{4.4.2.2}*

Co-benefits and adverse side effects of mitigation could affect achievement of other objectives such as those related to human health, food security, biodiversity, local environmental quality, energy access, livelihoods and equitable sustainable development. The potential for co-benefits for energy end-use measures outweighs the potential for adverse side effects whereas the evidence suggests this may not be the case for all energy supply and agriculture, forestry and other land use (AFOLU) measures. Some mitigation policies raise the prices for some energy services and could hamper the ability of societies to expand access to modern energy services to underserved populations (*low confidence*). These potential adverse side effects on energy access can be avoided with the adoption of complementary policies such as income tax rebates or other benefit transfer mechanisms (*medium confidence*). Whether or not side effects materialize, and to what extent side effects materialize, will be case- and site-specific, and depend on local circumstances and the scale, scope and pace of implementation. Many co-benefits and adverse side effects have not been well-quantified. *{4.3, 4.4.2.2, Box 3.4}*

Technology policy (development, diffusion and transfer) complements other mitigation policies across all scales, from international to sub-national; many adaptation efforts also critically rely on diffusion and transfer of technologies and management practices (*high confidence*). Policies exist to address market failures in R&D, but the effective use of technologies can also depend on capacities to adopt technologies appropriate to local circumstances. *{4.4.3}*

Substantial reductions in emissions would require large changes in investment patterns (*high confidence*). For mitigation scenarios that stabilize concentrations (without overshoot) in the range of 430 to 530 ppm CO_2-eq by 2100[19], annual investments in low carbon electricity supply and energy efficiency in key sectors (transport, industry and buildings) are projected in the scenarios to rise by several hundred billion dollars per year before 2030. Within appropriate enabling environments, the private sector, along with the public sector, can play important roles in financing mitigation and adaptation (*medium evidence, high agreement*). *{4.4.4}*

[19] This range comprises scenarios that reach 430 to 480 ppm CO_2-eq by 2100 (*likely* to limit warming to 2°C above pre-industrial levels) and scenarios that reach 480 to 530 ppm CO_2-eq by 2100 (without overshoot: *more likely than* not to limit warming to 2°C above pre-industrial levels).

Financial resources for adaptation have become available more slowly than for mitigation in both developed and developing countries. Limited evidence indicates that there is a gap between global adaptation needs and the funds available for adaptation (*medium confidence*). There is a need for better assessment of global adaptation costs, funding and investment. Potential synergies between international finance for disaster risk management and adaptation have not yet been fully realized (*high confidence*). *{4.4.4}*

SPM 4.5 Trade-offs, synergies and interactions with sustainable development

Climate change is a threat to sustainable development. Nonetheless, there are many opportunities to link mitigation, adaptation and the pursuit of other societal objectives through integrated responses (*high confidence*). Successful implementation relies on relevant tools, suitable governance structures and enhanced capacity to respond (*medium confidence*). *{3.5, 4.5}*

Climate change exacerbates other threats to social and natural systems, placing additional burdens particularly on the poor (*high confidence*). Aligning climate policy with sustainable development requires attention to both adaptation and mitigation (*high confidence*). Delaying global mitigation actions may reduce options for climate-resilient pathways and adaptation in the future. Opportunities to take advantage of positive synergies between adaptation and mitigation may decrease with time, particularly if limits to adaptation are exceeded. Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, encompassing connections among human health, water, energy, land use and biodiversity (*medium evidence, high agreement*). *{3.1, 3.5, 4.5}*

Strategies and actions can be pursued now which will move towards climate-resilient pathways for sustainable development, while at the same time helping to improve livelihoods, social and economic well-being and effective environmental management. In some cases, economic diversification can be an important element of such strategies. The effectiveness of integrated responses can be enhanced by relevant tools, suitable governance structures and adequate institutional and human capacity (*medium confidence*). Integrated responses are especially relevant to energy planning and implementation; interactions among water, food, energy and biological carbon sequestration; and urban planning, which provides substantial opportunities for enhanced resilience, reduced emissions and more sustainable development (*medium confidence*). *{3.5, 4.4, 4.5}*

Climate Change 2014
Synthesis Report

Introduction

Introduction

The Synthesis Report (SYR) of the IPCC Fifth Assessment Report (AR5) provides an overview of the state of knowledge concerning the science of climate change, emphasizing new results since the publication of the IPCC Fourth Assessment Report (AR4) in 2007. The SYR synthesizes the main findings of the AR5 based on contributions from Working Group I (*The Physical Science Basis*), Working Group II (*Impacts, Adaptation and Vulnerability*) and Working Group III (*Mitigation of Climate Change*), plus two additional IPCC reports (*Special Report on Renewable Energy Sources and Climate Change Mitigation* and *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*).

The AR5 SYR longer report is divided into four topics. Topic 1 (Observed Changes and their Causes) focuses on observational evidence for a changing climate, the impacts caused by this change and the human contributions to it. Topic 2 (Future Climate Changes, Risks and Impacts) assesses projections of future climate change and the resultant projected impacts and risks. Topic 3 (Future Pathways for Adaptation, Mitigation and Sustainable Development) considers adaptation and mitigation as complementary strategies for reducing and managing the risks of climate change. Topic 4 (Adaptation and Mitigation) describes individual adaptation and mitigation options and policy approaches. It also addresses integrated responses that link mitigation and adaptation with other societal objectives.

The challenges of understanding and managing risks and uncertainties are important themes in this report. See Box 1 (Risk and the Management of an Uncertain Future) and Box 2 (Communicating the Degree of Certainty in Assessment Findings).

This report includes information relevant to Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC).

Box Introduction.1 | Risk and the Management of an Uncertain Future

Climate change exposes people, societies, economic sectors and ecosystems to risk. Risk is the potential for consequences when something of value is at stake and the outcome is uncertain, recognizing the diversity of values. *{WGII SPM Background Box SPM.2, WGIII 2.1, SYR Glossary}*

Risks from climate change impacts arise from the interaction between hazard (triggered by an event or trend related to climate change), vulnerability (susceptibility to harm) and exposure (people, assets or ecosystems at risk). Hazards include processes that range from brief events, such as severe storms, to slow trends, such as multi-decade droughts or multi-century sea level rise. Vulnerability and exposure are both sensitive to a wide range of social and economic processes, with possible increases or decreases depending on development pathways. Risks and co-benefits also arise from policies that aim to mitigate climate change or to adapt to it. (1.5)

Risk is often represented as the probability of occurrence of hazardous events or trends multiplied by the magnitude of the consequences if these events occur. Therefore, high risk can result not only from high probability outcomes but also from low probability outcomes with very severe consequences. This makes it important to assess the full range of possible outcomes, from low probability tail outcomes to very likely outcomes. For example, it is unlikely that global mean sea level will rise by more than one meter in this century, but the consequence of a greater rise could be so severe that this possibility becomes a significant part of risk assessment. Similarly, low confidence but high consequence outcomes are also policy relevant; for instance the possibility that the response of Amazon forest could substantially amplify climate change merits consideration despite our currently imperfect ability to project the outcome. (2.4, Table 2.3) *{WGI Table 13.5, WGII SPM A-3, 4.4, Box 4-3, WGIII Box 3-9, SYR Glossary}*

Risk can be understood either qualitatively or quantitatively. It can be reduced and managed using a wide range of formal or informal tools and approaches that are often iterative. Useful approaches for managing risk do not necessarily require that risk levels can be accurately quantified. Approaches recognizing diverse qualitative values, goals and priorities, based on ethical, psychological, cultural or social factors, could increase the effectiveness of risk management. *{WGII 1.1.2, 2.4, 2.5, 19.3, WGIII 2.4, 2.5, 3.4}*

Box Introduction.2 | Communicating the Degree of Certainty in Assessment Findings

An integral feature of IPCC reports is the communication of the strength of and uncertainties in scientific understanding underlying assessment findings. Uncertainty can result from a wide range of sources. Uncertainties in the past and present are the result of limitations of available measurements, especially for rare events, and the challenges of evaluating causation in complex or multi-component processes that can span physical, biological and human systems. For the future, climate change involves changing likelihoods of diverse outcomes. Many processes and mechanisms are well understood, but others are not. Complex interactions among multiple climatic and non-climatic influences changing over time lead to persistent uncertainties, which in turn lead to the possibility of surprises. Compared to past IPCC reports, the AR5 assesses a substantially larger knowledge base of scientific, technical and socio-economic literature. *{WGI 1.4, WGII SPM A-3, 1.1.2, WGIII 2.3}*

The IPCC Guidance Note on Uncertainty[a] defines a common approach to evaluating and communicating the degree of certainty in findings of the assessment process. Each finding is grounded in an evaluation of underlying evidence and agreement. In many cases, a synthesis of evidence and agreement supports an assignment of confidence, especially for findings with stronger agreement and multiple independent lines of evidence. The degree of certainty in each key finding of the assessment is based on the type, amount, quality and consistency of evidence (e.g., data, mechanistic understanding, theory, models, expert judgment) and the degree of agreement. The summary terms for evidence are: limited, medium or robust. For agreement, they are low, medium or high. Levels of confidence include five qualifiers: very low, low, medium, high and very high, and are typeset in italics, e.g., *medium confidence*. The likelihood, or probability, of some well-defined outcome having occurred or occurring in the future can be described quantitatively through the following terms: virtually certain, 99–100% probability; extremely likely, 95–100%; very likely, 90–100%; likely, 66–100%; more likely than not, >50–100%; about as likely as not, 33–66%; unlikely, 0–33%; very unlikely, 0–10%; extremely unlikely, 0–5%; and exceptionally unlikely, 0–1%. Additional terms (extremely likely, 95–100%; more likely than not, >50–100%; more unlikely than likely, 0–<50%; and extremely unlikely, 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*. Unless otherwise indicated, findings assigned a likelihood term are associated with *high* or *very high confidence*. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers. *{WGI SPM B, WGII Background Box SPM.3, WGIII 2.1}*

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[a] Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L. Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.-K. Plattner, G.W. Yohe and F.W. Zwiers, 2010: Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties. Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland, 4 pp.

1 Observed Changes and their Causes

Topic 1: Observed Changes and their Causes

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.

Topic 1 focuses on observational evidence of a changing climate, the impacts caused by this change and the human contributions to it. It discusses observed changes in climate (1.1) and external influences on climate (forcings), differentiating those forcings that are of anthropogenic origin, and their contributions by economic sectors and greenhouse gases (GHGs) (1.2). Section 1.3 attributes observed climate change to its causes and attributes impacts on human and natural systems to climate change, determining the degree to which those impacts can be attributed to climate change. The changing probability of extreme events and their causes are discussed in Section 1.4, followed by an account of exposure and vulnerability within a risk context (1.5) and a section on adaptation and mitigation experience (1.6).

1.1 Observed changes in the climate system

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.

1.1.1 Atmosphere

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period from 1983 to 2012 was *very likely* the warmest 30-year period of the last 800 years in the Northern Hemisphere, where such assessment is possible (*high confidence*) and *likely* the warmest 30-year period of the last 1400 years (*medium confidence*). *{WGI 2.4.3, 5.3.5}*

The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06] °C[20] over the period 1880 to 2012, for which multiple independently produced datasets exist. The total increase between the average of the 1850–1900 period and the 2003–2012 period is 0.78 [0.72 to 0.85] °C, based on the single longest dataset available. For the longest period when calculation of regional trends is sufficiently complete (1901 to 2012), almost the entire globe has experienced surface warming (Figure 1.1). *{WGI SPM B.1, 2.4.3}*

In addition to robust multi-decadal warming, the globally averaged surface temperature exhibits substantial decadal and interannual variability (Figure 1.1). Due to this natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. As one example, the rate of warming over the past 15 years (1998–2012; 0.05 [–0.05 to 0.15] °C per decade), which begins with a strong El Niño, is smaller than the rate calculated since 1951 (1951–2012; 0.12 [0.08 to 0.14] °C per decade; see Box 1.1). *{WGI SPM B.1, 2.4.3}*

Based on multiple independent analyses of measurements, it is *virtually certain* that globally the troposphere has warmed and the lower stratosphere has cooled since the mid-20th century. There is *medium confidence* in the rate of change and its vertical structure in the Northern Hemisphere extratropical troposphere. *{WGI SPM B.1, 2.4.4}*

Confidence in precipitation change averaged over global land areas since 1901 is *low* prior to 1951 and *medium* afterwards. Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has *likely* increased since 1901 (*medium confidence* before and *high confidence* after 1951). For other latitudes area-averaged long-term positive or negative trends have *low confidence* (Figure 1.1). *{WGI SPM B.1, Figure SPM.2, 2.5.1}*

1.1.2 Ocean

Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*) with only about 1% stored in the atmosphere (Figure 1.2). On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 [0.09 to 0.13] °C per decade over the period 1971 to 2010. It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010, and it *likely* warmed between the 1870s and 1971. It is *likely* that the ocean warmed from 700 to 2000 m from 1957 to 2009 and from 3000 m to the bottom for the period 1992 to 2005 (Figure 1.2). *{WGI SPM B.2, 3.2, Box 3.1}*

It is *very likely* that regions of high surface salinity, where evaporation dominates, have become more saline, while regions of low salinity, where precipitation dominates, have become fresher since the 1950s. These regional trends in ocean salinity provide indirect evidence for changes in evaporation and precipitation over the oceans and thus for changes in the global water cycle (*medium confidence*). There is no observational evidence of a long-term trend in the Atlantic Meridional Overturning Circulation (AMOC). *{WGI SPM B.2, 2.5, 3.3, 3.4.3, 3.5, 3.6.3}*

[20] Ranges in square brackets indicate a 90% uncertainty interval unless otherwise stated. The 90% uncertainty interval is expected to have a 90% likelihood of covering the value that is being estimated. Uncertainty intervals are not necessarily symmetric about the corresponding best estimate. A best estimate of that value is also given where available.

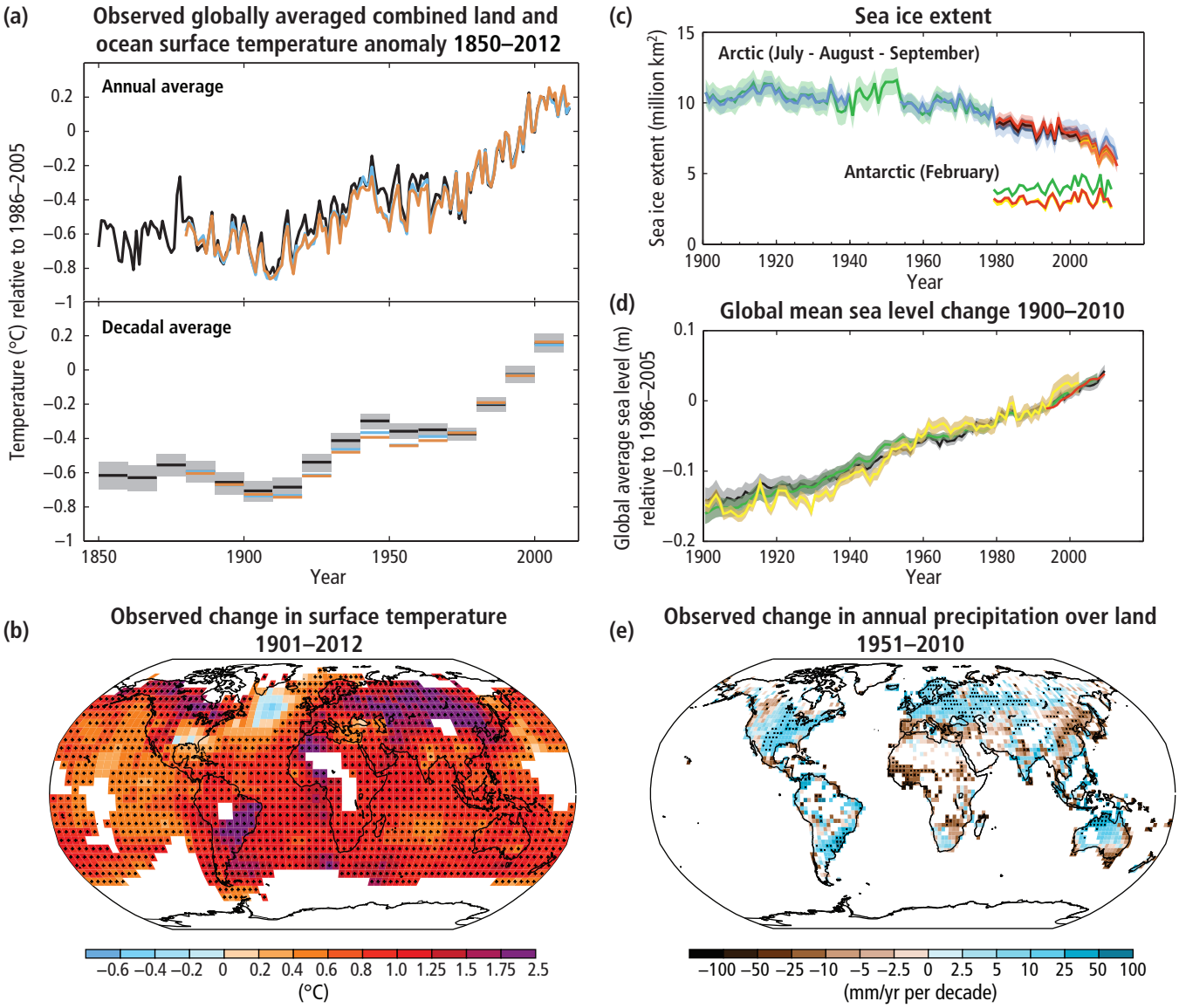


Figure 1.1 | Multiple observed indicators of a changing global climate system. **(a)** Observed globally averaged combined land and ocean surface temperature anomalies (relative to the mean of 1986 to 2005 period, as annual and decadal averages) with an estimate of decadal mean uncertainty included for one data set (grey shading). *{WGI Figure SPM.1, Figure 2.20; a listing of data sets and further technical details are given in the WGI Technical Summary Supplementary Material WGI TS.SM.1.1}* **(b)** Map of the observed surface temperature change, from 1901 to 2012, derived from temperature trends determined by linear regression from one data set (orange line in Panel a). Trends have been calculated where data availability permitted a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period), other areas are white. Grid boxes where the trend is significant, at the 10% level, are indicated by a + sign. *{WGI Figure SPM.1, Figure 2.21, Figure TS.2; a listing of data sets and further technical details are given in the WGI Technical Summary Supplementary Material WGI TS.SM.1.2}* **(c)** Arctic (July to September average) and Antarctic (February) sea ice extent. *{WGI Figure SPM.3, Figure 4.3, Figure 4.SM.2; a listing of data sets and further technical details are given in the WGI Technical Summary Supplementary Material WGI TS.SM.3.2}*. **(d)** Global mean sea level relative to the 1986–2005 mean of the longest running data set, and with all data sets aligned to have the same value in 1993, the first year of satellite altimetry data. All time series (coloured lines indicating different data sets) show annual values, and where assessed, uncertainties are indicated by coloured shading. *{WGI Figure SPM.3, Figure 3.13; a listing of data sets and further technical details are given in the WGI Technical Summary Supplementary Material WGI TS.SM.3.4}*. **(e)** Map of observed precipitation change, from 1951 to 2010; trends in annual accumulation calculated using the same criteria as in Panel b. *{WGI Figure SPM.2, TS TFE.1, Figure 2, Figure 2.29. A listing of data sets and further technical details are given in the WGI Technical Summary Supplementary Material WGI TS.SM.2.1}*

Since the beginning of the industrial era, oceanic uptake of CO_2 has resulted in acidification of the ocean; the pH of ocean surface water has decreased by 0.1 (*high confidence*), corresponding to a 26% increase in acidity, measured as hydrogen ion concentration. There is *medium confidence* that, in parallel to warming, oxygen concentrations have decreased in coastal waters and in the open ocean thermocline in many ocean regions since the 1960s, with a *likely* expansion of tropical oxygen minimum zones in recent decades. *{WGI SPM B.5, TS2.8.5, 3.8.1, 3.8.2, 3.8.3, 3.8.5, Figure 3.20}*

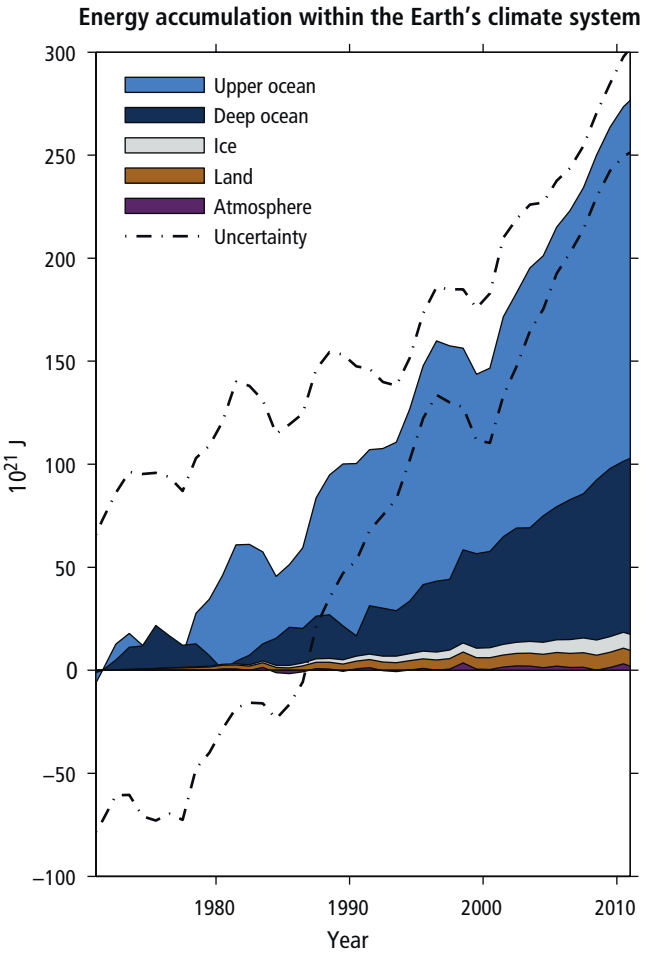


Figure 1.2 | Energy accumulation within the Earth's climate system. Estimates are in 10^{21} J, and are given relative to 1971 and from 1971 to 2010, unless otherwise indicated. Components included are upper ocean (above 700 m), deep ocean (below 700 m; including below 2000 m estimates starting from 1992), ice melt (for glaciers and ice caps, Greenland and Antarctic ice sheet estimates starting from 1992, and Arctic sea ice estimate from 1979 to 2008), continental (land) warming, and atmospheric warming (estimate starting from 1979). Uncertainty is estimated as error from all five components at 90% confidence intervals. *{WGI Box 3.1, Figure 1}*

1.1.3 Cryosphere

Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass (*high confidence*). Glaciers have continued to shrink almost worldwide (*high confidence*). Northern Hemisphere spring snow cover has continued to decrease in extent (*high confidence*). There is *high confidence* that there are strong regional differences in the trend in Antarctic sea ice extent, with a *very likely* increase in total extent. *{WGI SPM B.3, 4.2–4.7}*

Glaciers have lost mass and contributed to sea level rise throughout the 20th century. The rate of ice mass loss from the Greenland ice sheet has *very likely* substantially increased over the period 1992 to 2011, resulting in a larger mass loss over 2002 to 2011 than over 1992 to 2011. The rate of ice mass loss from the Antarctic ice sheet, mainly from the northern Antarctic Peninsula and the Amundsen Sea sector of West Antarctica, is also *likely* larger over 2002 to 2011. *{WGI SPM B.3, SPM B.4, 4.3.3, 4.4.2, 4.4.3}*

The annual mean Arctic sea ice extent decreased over the period 1979 (when satellite observations commenced) to 2012. The rate of decrease was *very likely* in the range 3.5 to 4.1% per decade. Arctic sea ice extent has decreased in every season and in every successive decade since 1979, with the most rapid decrease in decadal mean extent in summer (*high confidence*). For the summer sea ice minimum, the decrease was *very likely* in the range of 9.4 to 13.6% per decade (range of 0.73 to 1.07 million km^2 per decade) (see Figure 1.1). It is *very likely* that the annual mean Antarctic sea ice extent increased in the range of 1.2 to 1.8% per decade (range of 0.13 to 0.20 million km^2 per decade) between 1979 and 2012. However, there is *high confidence* that there are strong regional differences in Antarctica, with extent increasing in some regions and decreasing in others. *{WGI SPM B.5, 4.2.2, 4.2.3}*

There is *very high confidence* that the extent of Northern Hemisphere snow cover has decreased since the mid-20th century by 1.6 [0.8 to 2.4] % per decade for March and April, and 11.7% per decade for June, over the 1967 to 2012 period. There is *high confidence* that permafrost temperatures have increased in most regions of the Northern Hemisphere since the early 1980s, with reductions in thickness and areal extent in some regions. The increase in permafrost temperatures has occurred in response to increased surface temperature and changing snow cover. *{WGI SPM B.3, 4.5, 4.7.2}*

1.1.4 Sea level

Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] m (Figure 1.1). The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*). *{WGI SPM B.4, 3.7.2, 5.6.3, 13.2}*

It is *very likely* that the mean rate of global averaged sea level rise was 1.7 [1.5 to 1.9] mm/yr between 1901 and 2010 and 3.2 [2.8 to 3.6] mm/yr between 1993 and 2010. Tide gauge and satellite altimeter data are consistent regarding the higher rate during the latter period. It is *likely* that similarly high rates occurred between 1920 and 1950. *{WGI SPM B.4, 3.7, 13.2}*

Since the early 1970s, glacier mass loss and ocean thermal expansion from warming together explain about 75% of the observed global mean sea level rise (*high confidence*). Over the period 1993–2010, global mean sea level rise is, with *high confidence*, consistent with the sum of the observed contributions from ocean thermal expansion, due to warming, from changes in glaciers, the Greenland ice sheet, the Antarctic ice sheet and land water storage. *{WGI SPM B.4, 13.3.6}*

Rates of sea level rise over broad regions can be several times larger or smaller than the global mean sea level rise for periods of several decades, due to fluctuations in ocean circulation. Since 1993, the regional rates for the Western Pacific are up to three times larger than the global mean, while those for much of the Eastern Pacific are near zero or negative. *{WGI 3.7.3, FAQ 13.1}*

There is *very high confidence* that maximum global mean sea level during the last interglacial period (129,000 to 116,000 years ago) was, for several thousand years, at least 5 m higher than present and

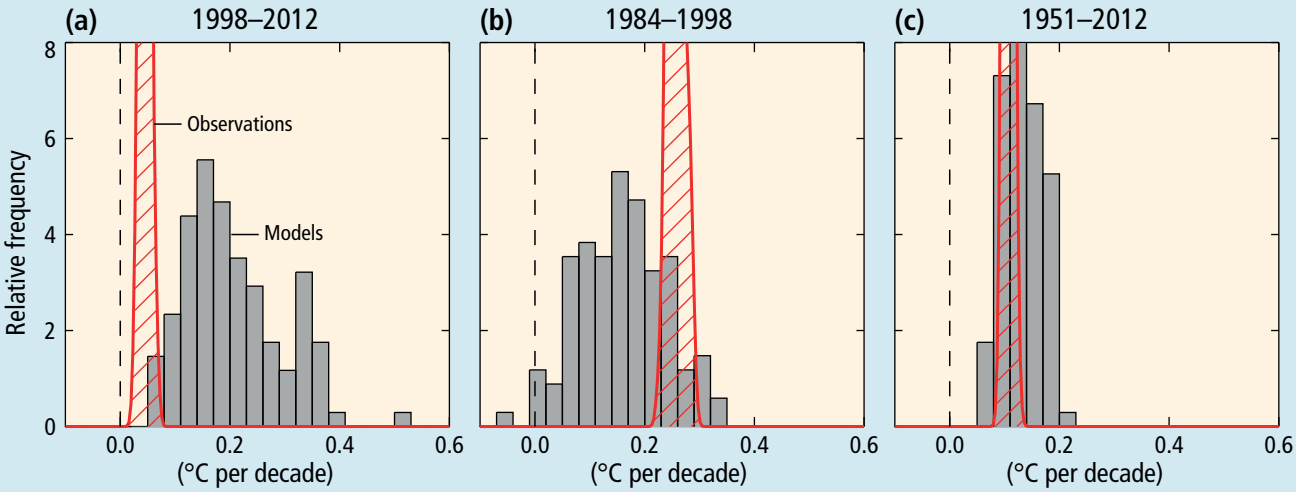
Box 1.1 | Recent Temperature Trends and their Implications

The observed reduction in surface warming trend over the period 1998 to 2012 as compared to the period 1951 to 2012, is due in roughly equal measure to a reduced trend in radiative forcing and a cooling contribution from natural internal variability, which includes a possible redistribution of heat within the ocean (*medium confidence*). The rate of warming of the observed global mean surface temperature over the period from 1998 to 2012 is estimated to be around one-third to one-half of the trend over the period from 1951 to 2012 (Box 1.1, Figures 1a and 1c). Even with this reduction in surface warming trend, the climate system has *very likely* continued to accumulate heat since 1998 (Figure 1.2) and sea level has continued to rise (Figure 1.1). *{WGI SPM D.1, Box 9.2}*

The radiative forcing of the climate system has continued to increase during the 2000s, as has its largest contributor, the atmospheric concentration of CO_2. However, the radiative forcing has been increasing at a lower rate over the period from 1998 to 2011, compared to 1984 to 1998 or 1951 to 2011, due to cooling effects from volcanic eruptions and the cooling phase of the solar cycle over the period from 2000 to 2009. There is, however, *low confidence* in quantifying the role of the forcing trend in causing the reduction in the rate of surface warming. *{WGI 8.5.2, Box 9.2}*

For the period from 1998 to 2012, 111 of the 114 available climate-model simulations show a surface warming trend larger than the observations (Box 1.1, Figure 1a). There is *medium confidence* that this difference between models and observations is to a substantial degree caused by natural internal climate variability, which sometimes enhances and sometimes counteracts the long-term externally forced warming trend (compare Box 1.1, Figures 1a and 1b; during the period from 1984 to 1998, most model simulations show a smaller warming trend than observed). Natural internal variability thus diminishes the relevance of short trends for long-term climate change. The difference between models and observations may also contain contributions from inadequacies in the solar, volcanic and aerosol forcings used by the models and, in some models, from an overestimate of the response to increasing greenhouse gas and other anthropogenic forcing (the latter dominated by the effects of aerosols). *{WGI 2.4.3, Box 9.2, 9.4.1, 10.3.1.1}*

For the longer period from 1951 to 2012, simulated surface warming trends are consistent with the observed trend (*very high confidence*) (Box 1.1, Figure 1c). Furthermore, the independent estimates of radiative forcing, of surface warming and of observed heat storage (the latter available since 1970) combine to give a heat budget for the Earth that is consistent with the assessed *likely* range of equilibrium climate sensitivity (1.5–4.5 °C)[21]. The record of observed climate change has thus allowed characterization of the basic properties of the climate system that have implications for future warming, including the equilibrium climate sensitivity and the transient climate response (see Topic 2). *{WGI Box 9.2, 10.8.1, 10.8.2, Box 12.2, Box 13.1}*



Box 1.1, Figure 1 | Trends in the global mean surface temperature over the periods from 1998 to 2012 **(a)**, 1984 to 1998 **(b)**, and 1951 to 2012 **(c)**, from observations (red) and the 114 available simulations with current-generation climate models (grey bars). The height of each grey bar indicates how often a trend of a certain magnitude (in °C per decade) occurs among the 114 simulations. The width of the red-hatched area indicates the statistical uncertainty that arises from constructing a global average from individual station data. This observational uncertainty differs from the one quoted in the text of Section 1.1.1; there, an estimate of natural internal variability is also included. Here, by contrast, the magnitude of natural internal variability is characterised by the spread of the model ensemble. *{based on WGI Box 9.2, Figure 1}*

[21] The connection between the heat budget and equilibrium climate sensitivity, which is the long-term surface warming under an assumed doubling of the atmospheric CO_2 concentration, arises because a warmer surface causes enhanced radiation to space which counteracts the increase in the Earth's heat content. How much the radiation to space increases for a given increase in surface temperature depends on the same feedback processes (e.g., cloud feedback, water vapour feedback) that determine equilibrium climate sensitivity.

high confidence that it did not exceed 10 m above present. During the last interglacial period, the Greenland ice sheet *very likely* contributed between 1.4 and 4.3 m to the higher global mean sea level, implying with *medium confidence* an additional contribution from the Antarctic ice sheet. This change in sea level occurred in the context of different orbital forcing and with high-latitude surface temperature, averaged over several thousand years, at least 2°C warmer than present (*high confidence*). *{WGI SPM B.4, 5.3.4, 5.6.2, 13.2.1}*

1.2 Past and recent drivers of climate change

Anthropogenic greenhouse gas emissions have increased since the pre-industrial era driven largely by economic and population growth. From 2000 to 2010 emissions were the highest in history. Historical emissions have driven atmospheric concentrations of carbon dioxide, methane and nitrous oxide to levels that are unprecedented in at least the last 800,000 years, leading to an uptake of energy by the climate system.

Natural and anthropogenic substances and processes that alter the Earth's energy budget are physical drivers of climate change. Radiative forcing quantifies the perturbation of energy into the Earth system caused by these drivers. Radiative forcings larger than zero lead to a near-surface warming, and radiative forcings smaller than zero lead to a cooling. Radiative forcing is estimated based on in-situ and remote observations, properties of GHGs and aerosols, and calculations using numerical models. The radiative forcing over the 1750–2011 period is shown in Figure 1.4 in major groupings. The 'Other Anthropogenic' group is principally comprised of cooling effects from aerosol changes, with smaller contributions from ozone changes, land use reflectance changes and other minor terms. *{WGI SPM C, 8.1, 8.5.1}*

1.2.1 Natural and anthropogenic radiative forcings

Atmospheric concentrations of GHGs are at levels that are unprecedented in at least 800,000 years. Concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have all shown large increases since 1750 (40%, 150% and 20%, respectively) (Figure 1.3). CO_2 concentrations are increasing at the fastest observed decadal rate of change (2.0 ± 0.1 ppm/yr) for 2002–2011. After almost one decade of stable CH_4 concentrations since the late 1990s, atmospheric measurements have shown renewed increases since 2007. N_2O concentrations have steadily increased at a rate of 0.73 ± 0.03 ppb/yr over the last three decades. *{WGI SPM B5, 2.2.1, 6.1.2, 6.1.3, 6.3}*

The total anthropogenic radiative forcing over 1750–2011 is calculated to be a warming effect of 2.3 [1.1 to 3.3] W/m² (Figure 1.4), and it has increased more rapidly since 1970 than during prior decades. Carbon dioxide is the largest single contributor to radiative forcing over 1750–2011 and its trend since 1970. The total anthropogenic radiative forcing estimate for 2011 is substantially higher (43%) than the estimate reported in the IPCC Fourth Assessment Report (AR4) for the year 2005. This is caused by a combination of continued growth in most GHG concentrations and an improved estimate of radiative forcing from aerosols. *{WGI SPM C, 8.5.1}*

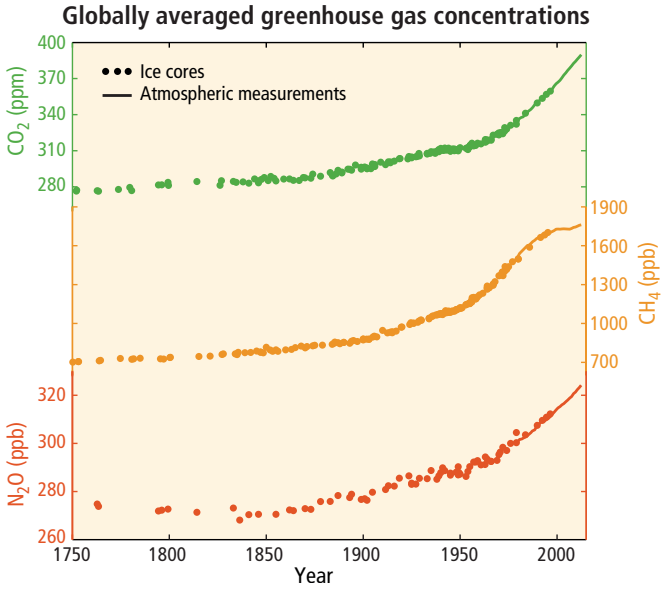


Figure 1.3 | Observed changes in atmospheric greenhouse gas concentrations. Atmospheric concentrations of carbon dioxide (CO_2, green), methane (CH_4, orange), and nitrous oxide (N_2O, red). Data from ice cores (symbols) and direct atmospheric measurements (lines) are overlaid. *{WGI 2.2, 6.2, 6.3, Figure 6.11}*

The radiative forcing from aerosols, which includes cloud adjustments, is better understood and indicates a weaker cooling effect than in AR4. The aerosol radiative forcing over 1750–2011 is estimated as –0.9 [–1.9 to –0.1] W/m² (*medium confidence*). Radiative forcing from aerosols has two competing components: a dominant cooling effect from most aerosols and their cloud adjustments and a partially offsetting warming contribution from black carbon absorption of solar radiation. There is *high confidence* that the global mean total aerosol radiative forcing has counteracted a substantial portion of radiative forcing from well-mixed GHGs. Aerosols continue to contribute the largest uncertainty to the total radiative forcing estimate. *{WGI SPM C, 7.5, 8.3, 8.5.1}*

Changes in solar irradiance and volcanic aerosols cause natural radiative forcing (Figure 1.4). The radiative forcing from stratospheric volcanic aerosols can have a large cooling effect on the climate system for some years after major volcanic eruptions. Changes in total solar irradiance are calculated to have contributed only around 2% of the total radiative forcing in 2011, relative to 1750. *{WGI SPM C, Figure SPM.5, 8.4}*

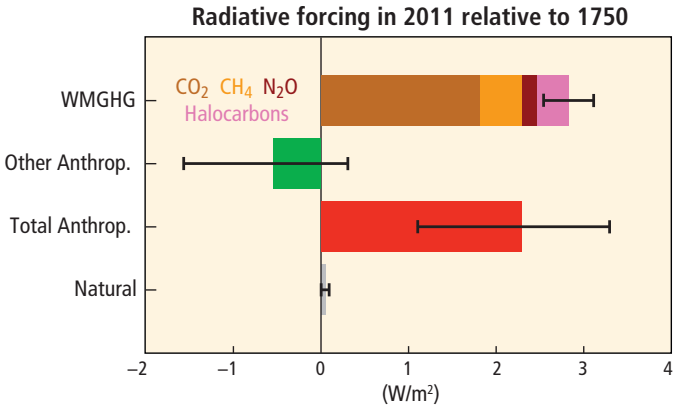


Figure 1.4 | Radiative forcing of climate change during the industrial era (1750–2011). Bars show radiative forcing from well-mixed greenhouse gases (WMGHG), other anthropogenic forcings, total anthropogenic forcings and natural forcings. The error bars indicate the 5 to 95% uncertainty. Other anthropogenic forcings include aerosol, land use surface reflectance and ozone changes. Natural forcings include solar and volcanic effects. The total anthropogenic radiative forcing for 2011 relative to 1750 is 2.3 W/m² (uncertainty range 1.1 to 3.3 W/m²). This corresponds to a CO_2-equivalent concentration (see Glossary) of 430 ppm (uncertainty range 340 to 520 ppm). *{Data from WGI 7.5 and Table 8.6}*

1.2.2 Human activities affecting emission drivers

About half of the cumulative anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years (*high confidence*). Cumulative anthropogenic CO_2 emissions of 2040 ± 310 $GtCO_2$ were added to the atmosphere between 1750 and 2011. Since 1970, cumulative CO_2 emissions from fossil fuel combustion, cement production and flaring have tripled, and cumulative CO_2 emissions from forestry and other land use (FOLU)[22] have increased by about 40% (Figure 1.5)[23]. In 2011, annual CO_2 emissions from fossil fuel combustion, cement production and flaring were 34.8 ± 2.9 $GtCO_2$/yr. For 2002–2011, average annual emissions from FOLU were 3.3 ± 2.9 $GtCO_2$/yr. *{WGI 6.3.1, 6.3.2, WGIII SPM.3}*

About 40% of these anthropogenic CO_2 emissions have remained in the atmosphere (880 ± 35 $GtCO_2$) since 1750. The rest was removed from the atmosphere by sinks, and stored in natural carbon cycle reservoirs. Sinks from ocean uptake and vegetation with soils account, in roughly equal measures, for the remainder of the cumulative CO_2 emissions. The ocean has absorbed about 30% of the emitted anthropogenic CO_2, causing ocean acidification. *{WGI 3.8.1, 6.3.1}*

Total annual anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute increases between 2000 and 2010 (*high confidence*). Despite a growing number of climate change mitigation policies, annual GHG emissions grew on average by 1.0 $GtCO_2$-eq (2.2%) per year, from 2000 to 2010, compared to 0.4 $GtCO_2$-eq (1.3%) per year, from 1970 to 2000 (Figure 1.6)[24]. Total anthropogenic GHG emissions from 2000 to 2010 were the highest in human history and reached 49 (±4.5) $GtCO_2$-eq/yr in 2010. The global economic crisis of 2007/2008 reduced emissions only temporarily. *{WGIII SPM.3, 1.3, 5.2, 13.3, 15.2.2, Box TS.5, Figure 15.1}*

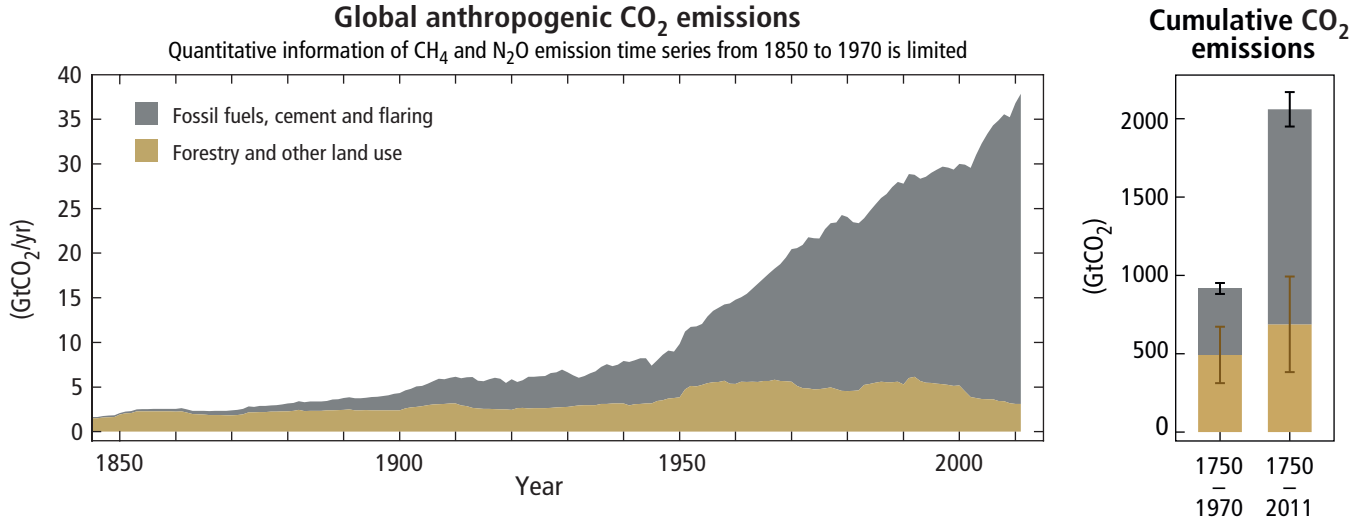


Figure 1.5 | Annual global anthropogenic carbon dioxide (CO_2) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$/yr) from fossil fuel combustion, cement production and flaring, and forestry and other land use (FOLU), 1750–2011. Cumulative emissions and their uncertainties are shown as bars and whiskers, respectively, on the right-hand side. The global effects of the accumulation of methane (CH_4) and nitrous oxide (N_2O) emissions are shown in Figure 1.3. Greenhouse gas emission data from 1970 to 2010 are shown in Figure 1.6. *{modified from WGI Figure TS.4 and WGIII Figure TS.2}*

[22] Forestry and other land use (FOLU)—also referred to as LULUCF (land use, land use change and forestry)—is the subset of agriculture, forestry and other land use (AFOLU) emissions and removals of GHGs related to direct human-induced LULUCF activities, excluding agricultural emissions and removals *(see WGIII AR5 Glossary)*.

[23] Numbers from WGI 6.3 converted into $GtCO_2$ units. Small differences in cumulative emissions from Working Group III *{WGIII SPM.3, TS.2.1}* are due to different approaches to rounding, different end years and the use of different data sets for emissions from FOLU. Estimates remain extremely close, given their uncertainties.

[24] CO_2-equivalent emission is a common scale for comparing emissions of different GHGs. Throughout the SYR, when historical emissions of GHGs are provided in $GtCO_2$-eq, they are weighted by Global Warming Potentials with a 100-year time horizon (GWP_{100}), taken from the IPCC Second Assessment Report unless otherwise stated. A unit abbreviation of $GtCO_2$-eq is used. *{Box 3.2, Glossary}*

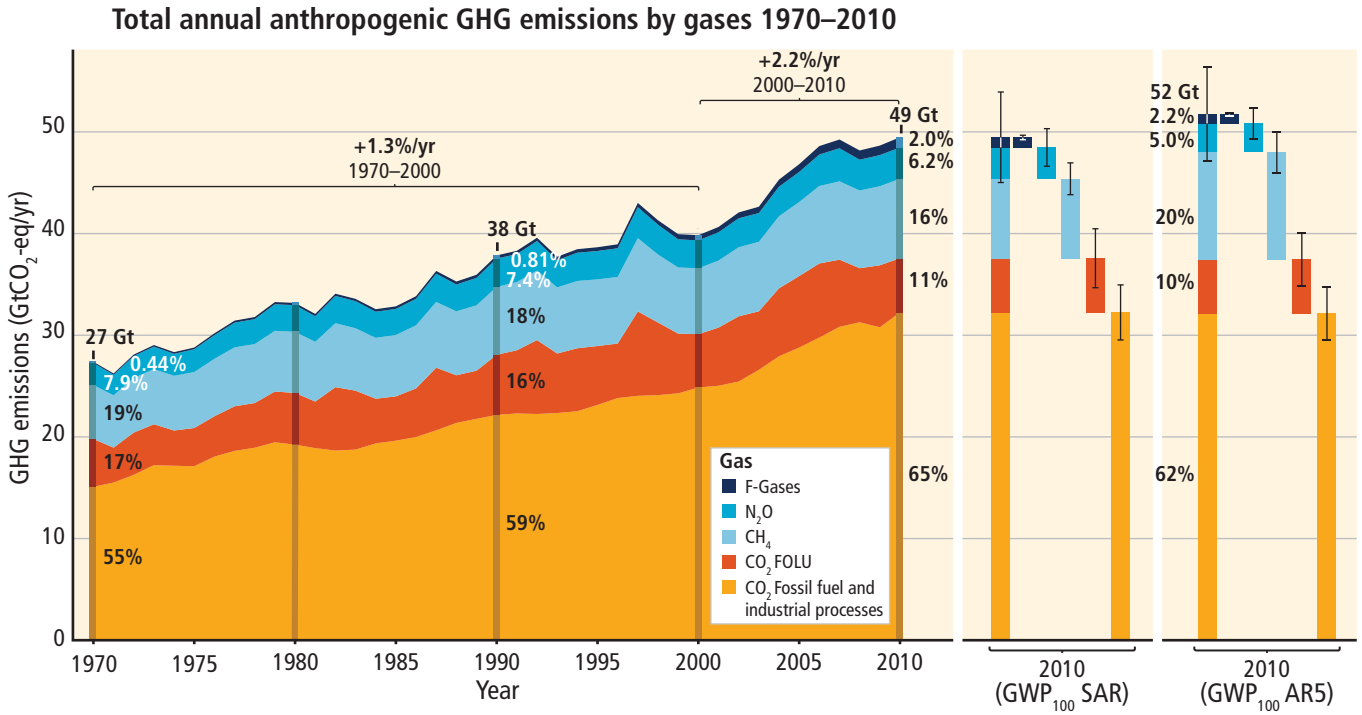


Figure 1.6 | Total annual anthropogenic greenhouse gas (GHG) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) for the period 1970 to 2010, by gases: CO_2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH_4); nitrous oxide (N_2O); fluorinated gases covered under the Kyoto Protocol (F-gases). Right hand side shows 2010 emissions, using alternatively CO_2-equivalent emission weightings based on IPCC Second Assessment Report (SAR) and AR5 values. Unless otherwise stated, CO_2-equivalent emissions in this report include the basket of Kyoto gases (CO_2, CH_4, N_2O as well as F-gases) calculated based on 100-year Global Warming Potential (GWP_{100}) values from the SAR (see Glossary). Using the most recent GWP_{100} values from the AR5 (right-hand bars) would result in higher total annual GHG emissions (52 $GtCO_2$-eq/yr) from an increased contribution of methane, but does not change the long-term trend significantly. Other metric choices would change the contributions of different gases (see Box 3.2). The 2010 values are shown again broken down into their components with the associated uncertainties (90% confidence interval) indicated by the error bars. Global CO_2 emissions from fossil fuel combustion are known with an 8% uncertainty margin (90% confidence interval). There are very large uncertainties (of the order of ±50%) attached to the CO_2 emissions from FOLU. Uncertainty about the global emissions of CH_4, N_2O and the F-gases has been estimated at 20%, 60% and 20%, respectively. 2010 was the most recent year for which emission statistics on all gases as well as assessments of uncertainties were essentially complete at the time of data cut off for this report. The uncertainty estimates only account for uncertainty in emissions, not in the GWPs (as given in WGI 8.7). *{WGIII Figure SPM.1}*

CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% to the total GHG emission increase between 1970 and 2010, with a contribution of similar percentage over the 2000–2010 period (*high confidence*). Fossil-fuel-related CO_2 emissions reached 32 (±2.7) $GtCO_2$/yr, in 2010, and grew further by about 3% between 2010 and 2011, and by about 1 to 2% between 2011 and 2012. CO_2 remains the major anthropogenic GHG, accounting for 76% of total anthropogenic GHG emissions in 2010. Of the total, 16% comes from CH_4, 6.2% from N_2O, and 2.0% from fluorinated gases (F-gases) (Figure 1.6)[25]. Annually, since 1970, about 25% of anthropogenic GHG emissions have been in the form of non-CO_2 gases[26]. *{WGIII SPM.3, 1.2, 5.2}*

Total annual anthropogenic GHG emissions have increased by about 10 $GtCO_2$-eq between 2000 and 2010. This increase directly came from the energy (47%), industry (30%), transport (11%) and building (3%) sectors (*medium confidence*). Accounting for indirect emissions raises the contributions by the building and industry sectors (*high confidence*). Since 2000, GHG emissions have been growing in all sectors, except in agriculture, forestry and other land use (AFOLU)[22]. In 2010, 35% of GHG emissions were released by the energy sector, 24% (net emissions) from AFOLU, 21% by industry, 14% by transport and 6.4% by the building sector. When emissions from electricity and heat production are attributed to the sectors that use the final energy (i.e., indirect emissions), the shares of the industry and building sectors in global GHG emissions are increased to 31% and 19%, respectively (Figure 1.7). *{WGIII SPM.3, 7.3, 8.1, 9.2, 10.3, 11.2}* See also Box 3.2 for contributions from various sectors, based on metrics other than 100-year Global Warming Potential (GWP_{100}).

Globally, economic and population growth continue to be the most important drivers of increases in CO_2 emissions from fossil fuel combustion. The contribution of population growth between 2000 and 2010 remained roughly identical to that of the previous three decades, while the contribution of economic growth has risen sharply (*high confidence*). Between 2000 and

[25] Using the most recent 100-year Global Warming Potential (GWP_{100}) values from the AR5 *{WGI 8.7}* instead of GWP_{100} values from the IPCC Second Assessment Report, global GHG emission totals would be slightly higher (52 $GtCO_2$-eq/yr) and non-CO_2 emission shares would be 20% for CH_4, 5% for N_2O and 2.2% for F-gases.

[26] For this report, data on non-CO_2 GHGs, including F-gases, were taken from the Electronic Data Gathering, Analysis, and Retrieval (EDGAR) database *{WGIII Annex II.9}*, which covers substances included in the Kyoto Protocol in its first commitment period.

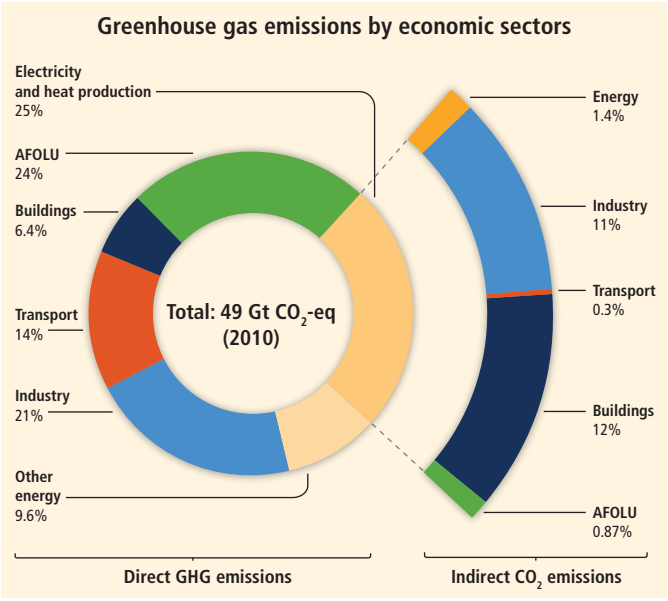


Figure 1.7 | Total anthropogenic greenhouse gas (GHG) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) from economic sectors in 2010. The circle shows the shares of direct GHG emissions (in % of total anthropogenic GHG emissions) from five economic sectors in 2010. The pull-out shows how shares of indirect CO_2 emissions (in % of total anthropogenic GHG emissions) from electricity and heat production are attributed to sectors of final energy use. 'Other energy' refers to all GHG emission sources in the energy sector as defined in WGIII Annex II, other than electricity and heat production *{WGIII Annex II.9.1}*. The emission data on agriculture, forestry and other land use (AFOLU) includes land-based CO_2 emissions from forest fires, peat fires and peat decay that approximate to net CO_2 flux from the sub-sectors of forestry and other land use (FOLU) as described in Chapter 11 of the WGIII report. Emissions are converted into CO_2-equivalents based on 100-year Global Warming Potential (GWP_{100}), taken from the IPCC Second Assessment Report (SAR). Sector definitions are provided in WGIII Annex II.9. *{WGIII Figure SPM.2}*

2010, both drivers outpaced emission reductions from improvements in energy intensity of gross domestic product (GDP) (Figure 1.8). Increased use of coal relative to other energy sources has reversed the long-standing trend in gradual decarbonization (i.e., reducing the carbon intensity of energy) of the world's energy supply. *{WGIII SPM.3, TS.2.2, 1.3, 5.3, 7.2, 7.3, 14.3}*

1.3 Attribution of climate changes and impacts

The evidence for human influence on the climate system has grown since AR4. Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, and in global mean sea level rise; and it is *extremely likely* to have been the dominant cause of the observed warming since the mid-20th century. In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate.

The causes of observed changes in the climate system, as well as in any natural or human system impacted by climate, are established following a consistent set of methods. Detection addresses the question of whether climate or a natural or human system affected by climate has actually changed in a statistical sense, while attribution evaluates the relative contributions of multiple causal factors to an observed change

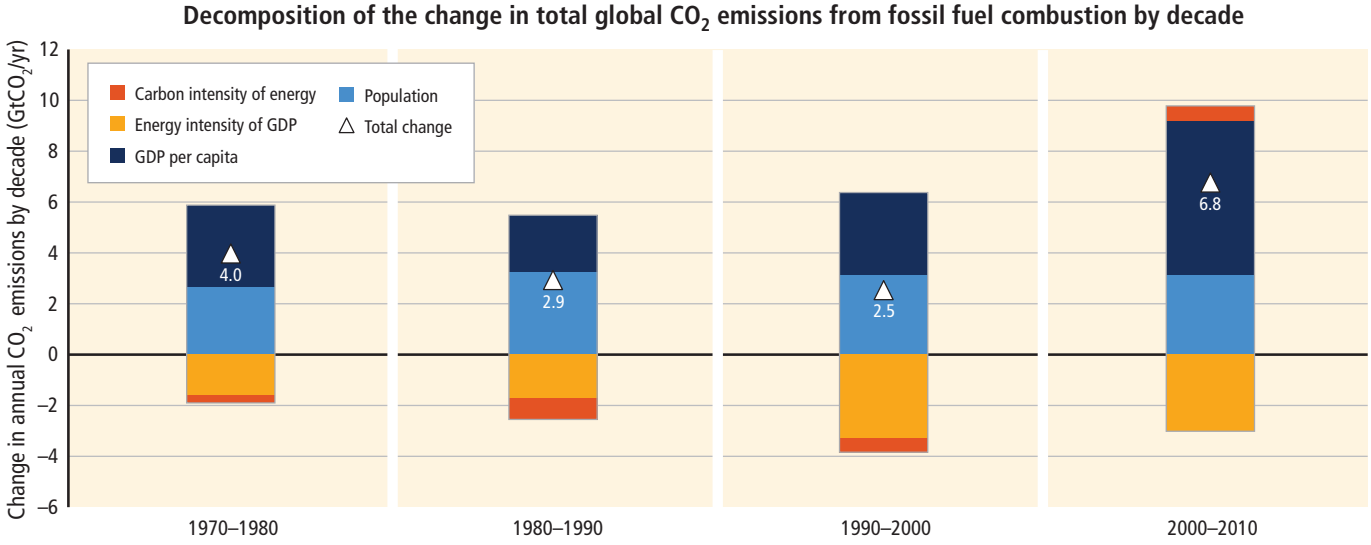


Figure 1.8 | Decomposition of the change in total annual carbon dioxide (CO_2) emissions from fossil fuel combustion by decade and four driving factors: population, income (gross domestic product, GDP) per capita, energy intensity of GDP and carbon intensity of energy. The bar segments show the changes associated with each individual factor, holding the respective other factors constant. Total emission changes are indicated by a triangle. The change in emissions over each decade is measured in gigatonnes of CO_2 per year ($GtCO_2$/yr); income is converted into common units, using purchasing power parities. *{WGIII SPM.3}*

or event with an assignment of statistical confidence[27]. Attribution of climate change to causes quantifies the links between observed climate change and human activity, as well as other, natural, climate drivers. In contrast, attribution of observed impacts to climate change considers the links between observed changes in natural or human systems and observed climate change, regardless of its cause. Results from studies attributing climate change to causes provide estimates of the magnitude of warming in response to changes in radiative forcing and hence support projections of future climate change (Topic 2). Results from studies attributing impacts to climate change provide strong indications for the sensitivity of natural or human systems to future climate change. *{WGI 10.8, WGII SPM A-1, WGI/II/III/SYR Glossaries}*

1.3.1 Attribution of climate changes to human and natural influences on the climate system

It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcings together (Figure 1.9). The best estimate of the human induced contribution to warming is similar to the observed warming over this period. GHGs contributed a global mean surface warming *likely* to be in the range of 0.5°C to 1.3°C over the period 1951 to 2010, with further contributions from other anthropogenic forcings, including the cooling effect of aerosols, from natural forcings, and from natural internal variability (see Figure 1.9).

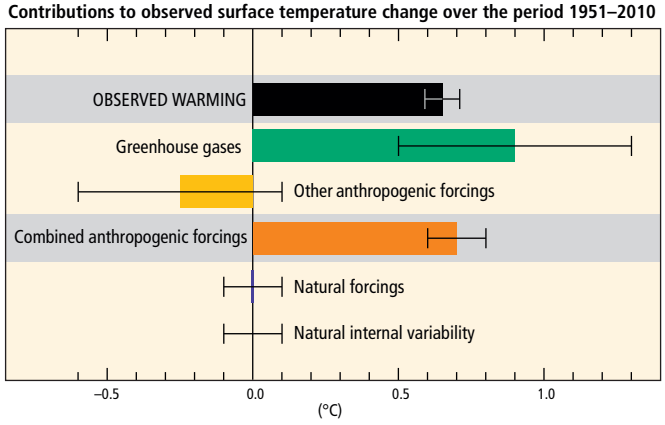


Figure 1.9 | Assessed *likely* ranges (whiskers) and their mid-points (bars) for warming trends over the 1951–2010 period from well-mixed greenhouse gases, other anthropogenic forcings (including the cooling effect of aerosols and the effect of land use change), combined anthropogenic forcings, natural forcings, and natural internal climate variability (which is the element of climate variability that arises spontaneously within the climate system, even in the absence of forcings). The observed surface temperature change is shown in black, with the 5 to 95% uncertainty range due to observational uncertainty. The attributed warming ranges (colours) are based on observations combined with climate model simulations, in order to estimate the contribution by an individual external forcing to the observed warming. The contribution from the combined anthropogenic forcings can be estimated with less uncertainty than the separate contributions from greenhouse gases and other anthropogenic forcings separately. This is because these two contributions partially compensate, resulting in a signal that is better constrained by observations. *{Based on Figure WGI TS.10}*

Together these assessed contributions are consistent with the observed warming of approximately 0.6°C to 0.7°C over this period. *{WGI SPM D.3, 10.3.1}*

It is *very likely* that anthropogenic influence, particularly GHGs and stratospheric ozone depletion, has led to a detectable observed pattern of tropospheric warming and a corresponding cooling in the lower stratosphere since 1961. *{WGI SPM D.3, 2.4.4, 9.4.1, 10.3.1}*

Over every continental region except Antarctica, anthropogenic forcings have *likely* made a substantial contribution to surface temperature increases since the mid-20th century (Figure 1.10). For Antarctica, large observational uncertainties result in *low confidence* that anthropogenic forcings have contributed to the observed warming averaged over available stations. In contrast, it is *likely* that there has been an anthropogenic contribution to the very substantial Arctic warming since the mid-20th century. Human influence has *likely* contributed to temperature increases in many sub-continental regions. *{WGI SPM D.3, TS.4.8, 10.3.1}*

Anthropogenic influences have *very likely* contributed to Arctic sea ice loss since 1979 (Figure 1.10). There is *low confidence* in the scientific understanding of the small observed increase in Antarctic sea ice extent due to the incomplete and competing scientific explanations for the causes of change and *low confidence* in estimates of natural internal variability in that region. *{WGI SPM D.3, 10.5.1, Figure 10.16}*

Anthropogenic influences *likely* contributed to the retreat of glaciers since the 1960s and to the increased surface melting of the Greenland ice sheet since 1993. Due to a low level of scientific understanding, however, there is *low confidence* in attributing the causes of the observed loss of mass from the Antarctic ice sheet over the past two decades. It is *likely* that there has been an anthropogenic contribution to observed reductions in Northern Hemisphere spring snow cover since 1970. *{WGI 4.3.3, 10.5.2, 10.5.3}*

It is *likely* that anthropogenic influences have affected the global water cycle since 1960. Anthropogenic influences have contributed to observed increases in atmospheric moisture content (*medium confidence*), to global-scale changes in precipitation patterns over land (*medium confidence*), to intensification of heavy precipitation over land regions where data are sufficient (*medium confidence*) (see 1.4) and to changes in surface and subsurface ocean salinity (*very likely*). *{WGI SPM D.3, 2.5.1, 2.6.2, 3.3.2, 3.3.3, 7.6.2, 10.3.2, 10.4.2, 10.6}*

It is *very likely* that anthropogenic forcings have made a substantial contribution to increases in global upper ocean heat content (0–700 m) observed since the 1970s (Figure 1.10). There is evidence for human influence in some individual ocean basins. It is *very likely* that there is a substantial anthropogenic contribution to the global mean sea level rise since the 1970s. This is based on the *high confidence* in an anthropogenic influence on the two largest contributions to sea level rise: thermal expansion and glacier mass loss. Oceanic

[27] Definitions were taken from the Good Practice Guidance Paper on Detection and Attribution, the agreed product of the IPCC Expert Meeting on Detection and Attribution Related to Anthropogenic Climate Change; see Glossary.

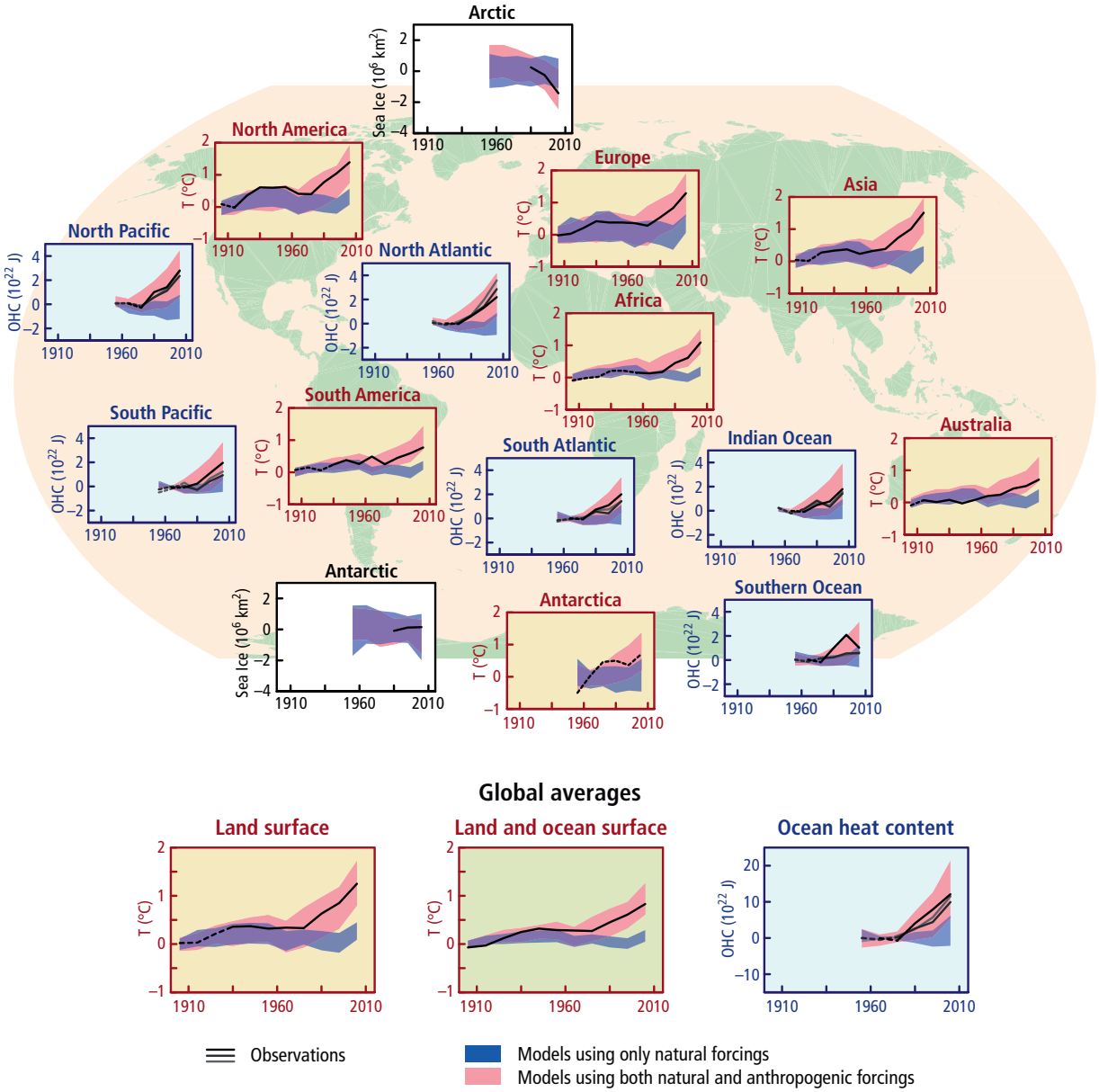


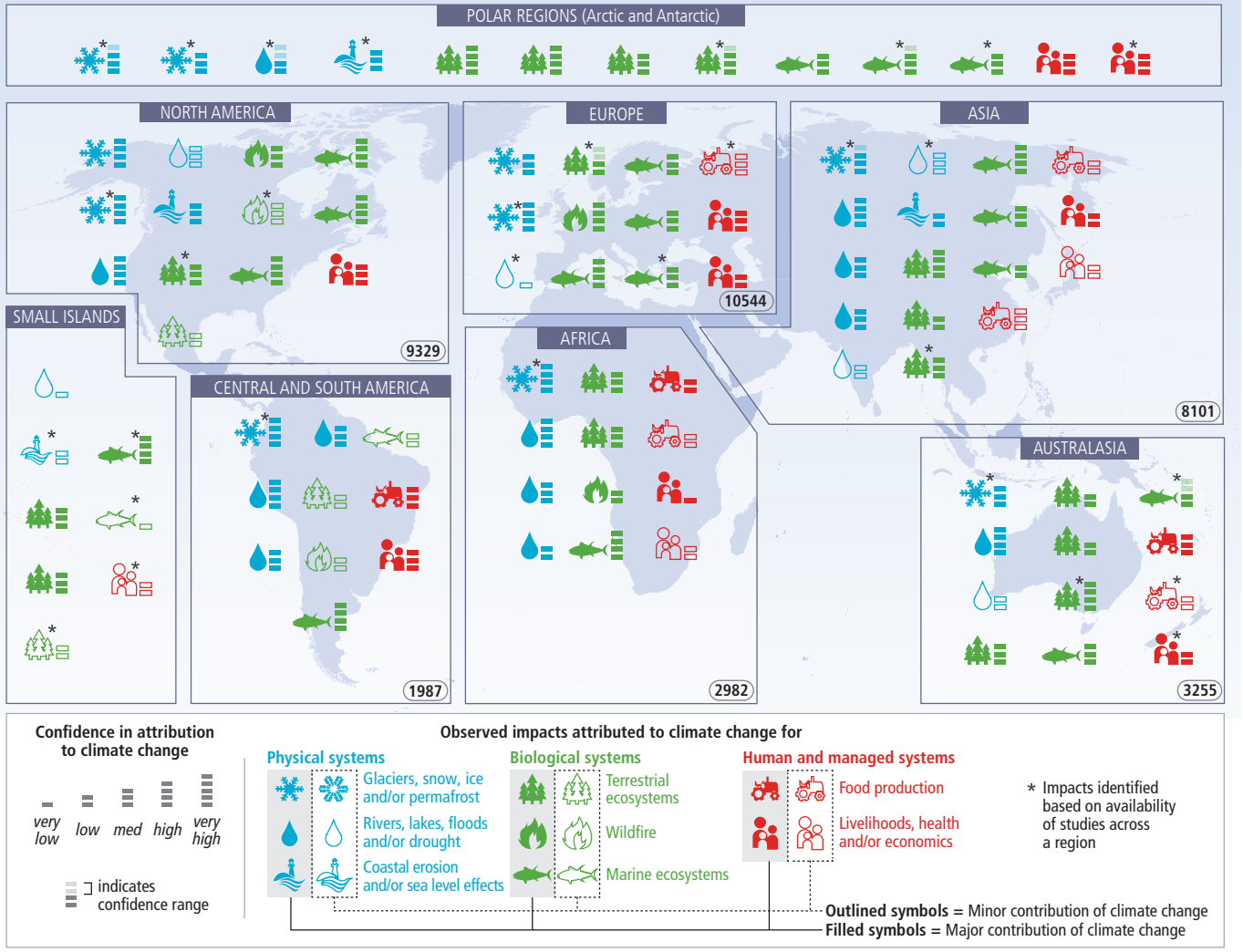
Figure 1.10 | Comparison of observed and simulated change in continental surface temperatures on land (yellow panels), Arctic and Antarctic September sea ice extent (white panels), and upper ocean heat content in the major ocean basins (blue panels). Global average changes are also given. Anomalies are given relative to 1880–1919 for surface temperatures, to 1960–1980 for ocean heat content, and to 1979–1999 for sea ice. All time series are decadal averages, plotted at the centre of the decade. For temperature panels, observations are dashed lines if the spatial coverage of areas being examined is below 50%. For ocean heat content and sea ice panels, the solid lines are where the coverage of data is good and higher in quality, and the dashed lines are where the data coverage is only adequate, and, thus, uncertainty is larger (note that different lines indicate different data sets; for details, see WGI Figure SPM.6). Model results shown are Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble ranges, with shaded bands indicating the 5 to 95% confidence intervals. *{WGI Figure SPM 6; for detail, see WGI Figure TS.12}*

uptake of anthropogenic CO_2 has resulted in gradual acidification of ocean surface waters (*high confidence*). *{WGI SPM D.3, 3.2.3, 3.8.2, 10.4.1, 10.4.3, 10.4.4, 10.5.2, 13.3, Box 3.2, TS.4.4, WGII 6.1.1.2, Box CC-OA}*

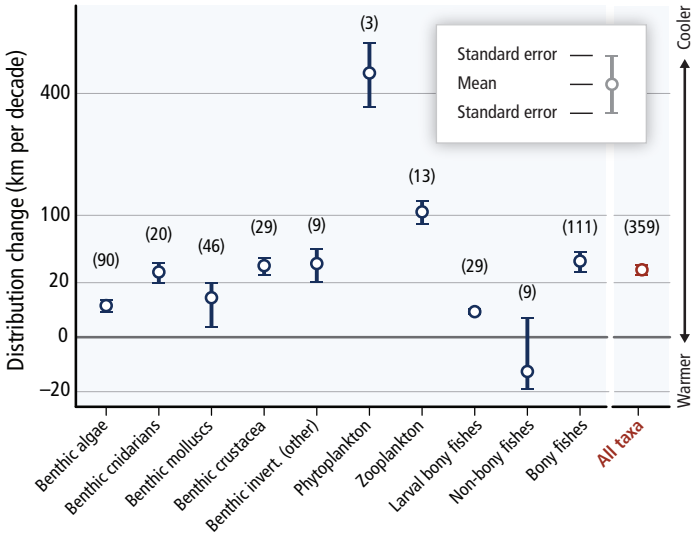
1.3.2 Observed impacts attributed to climate change

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate. Evidence of observed climate change impacts is strongest and most comprehensive for natural systems. Some impacts on human systems have also been attributed to climate change, with a major or minor contribution of climate change distinguishable from other influences (Figure 1.11). Impacts on human systems are often geographically heterogeneous because they depend not only on changes in climate variables but also on social and economic factors. Hence, the changes are more easily observed at local levels, while attribution can remain difficult. *{WGII SPM A-1, SPM A-3, 18.1, 18.3–18.6}*

(a) Widespread impacts attributed to climate change based on the available scientific literature since the AR4



(b)



(c)

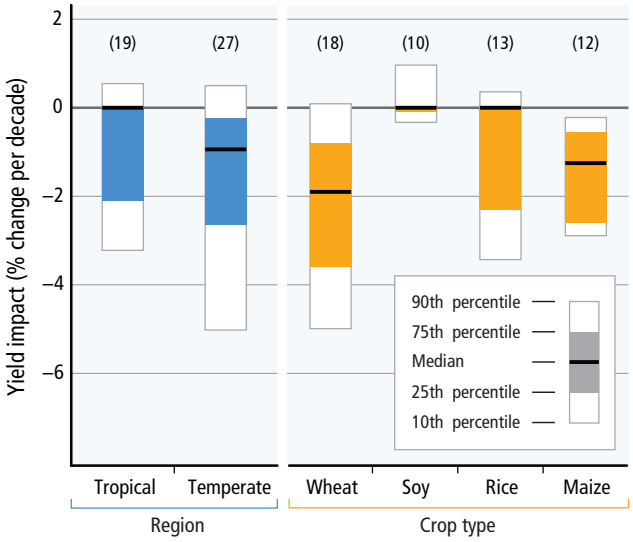




Figure 1.11 | Widespread impacts in a changing world: **(a)** Based on the available scientific literature since the IPCC Fourth Assessment Report (AR4), there are substantially more impacts in recent decades now attributed to climate change. Attribution requires defined scientific evidence on the role of climate change. Absence from the map of additional impacts attributed to climate change does not imply that such impacts have not occurred. The publications supporting attributed impacts reflect a growing knowledge base, but publications are still limited for many regions, systems and processes, highlighting gaps in data and studies. Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact and confidence in attribution. Each symbol refers to one or more entries in WGII Table SPM.A1, grouping related regional-scale impacts. Numbers in ovals indicate regional totals of climate change publications from 2001 to 2010, based on the Scopus bibliographic database for publications in English with individual countries mentioned in title, abstract or key words (as of July 2011). These numbers provide an overall measure of the available scientific literature on climate change across regions; they do not indicate the number of publications supporting attribution of climate change impacts in each region. Studies for polar regions and small islands are grouped with neighbouring continental regions. The inclusion of publications for assessment of attribution followed IPCC scientific evidence criteria defined in WGII Chapter 18. Publications considered in the attribution analyses come from a broader range of literature assessed in the WGII AR5. See WGII Table SPM.A1 for descriptions of the attributed impacts. **(b)** Average rates of change in distribution (km per decade) for marine taxonomic groups based on observations over 1900–2010. Positive distribution changes are consistent with warming (moving into previously cooler waters, generally poleward). The number of responses analysed is given for each category. **(c)** Summary of estimated impacts of observed climate changes on yields over 1960–2013 for four major crops in temperate and tropical regions, with the number of data points analysed given within parentheses for each category. *{WGII Figure SPM.2, Box TS.1 Figure 1}*

In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality (*medium confidence*). Glaciers continue to shrink almost worldwide due to climate change (*high confidence*), affecting runoff and water resources downstream (*medium confidence*). Climate change is causing permafrost warming and thawing in high-latitude regions and in high-elevation regions (*high confidence*). *{WGII SPM A-1}*

Many terrestrial, freshwater and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances and species interactions in response to ongoing climate change (*high confidence*). While only a few recent species extinctions have been attributed as yet to climate change (*high confidence*), natural global climate change at rates slower than current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years (*high confidence*). Increased tree mortality, observed in many places worldwide, has been attributed to climate change in some regions. Increases in the frequency or intensity of ecosystem disturbances such as droughts, windstorms, fires and pest outbreaks have been detected in many parts of the world and in some cases are attributed to climate change (*medium confidence*). Numerous observations over the last decades in all ocean basins show changes in abundance, distribution shifts poleward and/or to deeper, cooler waters for marine fishes, invertebrates and phytoplankton (*very high confidence*), and altered ecosystem composition (*high confidence*), tracking climate trends. Some warm-water corals and their reefs have responded to warming with species replacement, bleaching, and decreased coral cover causing habitat loss (*high confidence*). Some impacts of ocean acidification on marine organisms have been attributed to human influence, from the thinning of pteropod and foraminiferan shells (*medium confidence*) to the declining growth rates of corals (*low confidence*). Oxygen minimum zones are progressively expanding in the tropical Pacific, Atlantic and Indian Oceans, due to reduced ventilation and O_2 solubility in warmer, more stratified oceans, and are constraining fish habitat (*medium confidence*). *{WGII SPM A-1, Table SPM.A1, TS A-1, 6.3.2.5, 6.3.3, 18.3–18.4, 30.5.1.1, Box CC-OA, Box CC-CR}*

Assessment of many studies covering a wide range of regions and crops shows that negative impacts of climate change on crop yields have been more common than positive impacts (*high confidence*). The smaller number of studies showing positive impacts relate mainly to high-latitude regions, though it is not yet clear whether the balance of impacts has been negative or positive in these regions (*high confidence*). Climate change has negatively affected wheat and maize yields for many regions and in the global aggregate (*medium confidence*). Effects on rice and soybean yield have been smaller in major production regions and globally, with a median change of zero across all available data which are fewer for soy compared to the other crops (see Figure 1.11c). Observed impacts relate mainly to production aspects of food security rather than access or other components of food security. Since AR4, several periods of rapid food and cereal price increases following climate extremes in key producing regions indicate a sensitivity of current markets to climate extremes among other factors (*medium confidence*). *{WGII SPM A-1}*

At present the worldwide burden of human ill-health from climate change is relatively small compared with effects of other stressors and is not well quantified. However, there has been increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming (*medium confidence*). Local changes in temperature and rainfall have altered the distribution of some water-borne illnesses and disease vectors (*medium confidence*). *{WGII SPM A-1}*

'Cascading' impacts of climate change can now be attributed along chains of evidence from physical climate through to intermediate systems and then to people (Figure 1.12). The changes in climate feeding into the cascade, in some cases, are linked to human drivers (e.g., a decreasing amount of water in spring snowpack in western North America), while, in other cases, assessments of the causes of observed climate change leading into the cascade are not available. In all cases, confidence in detection and attribution to observed climate change decreases for effects further down each impact chain. *{WGII 18.6.3}*

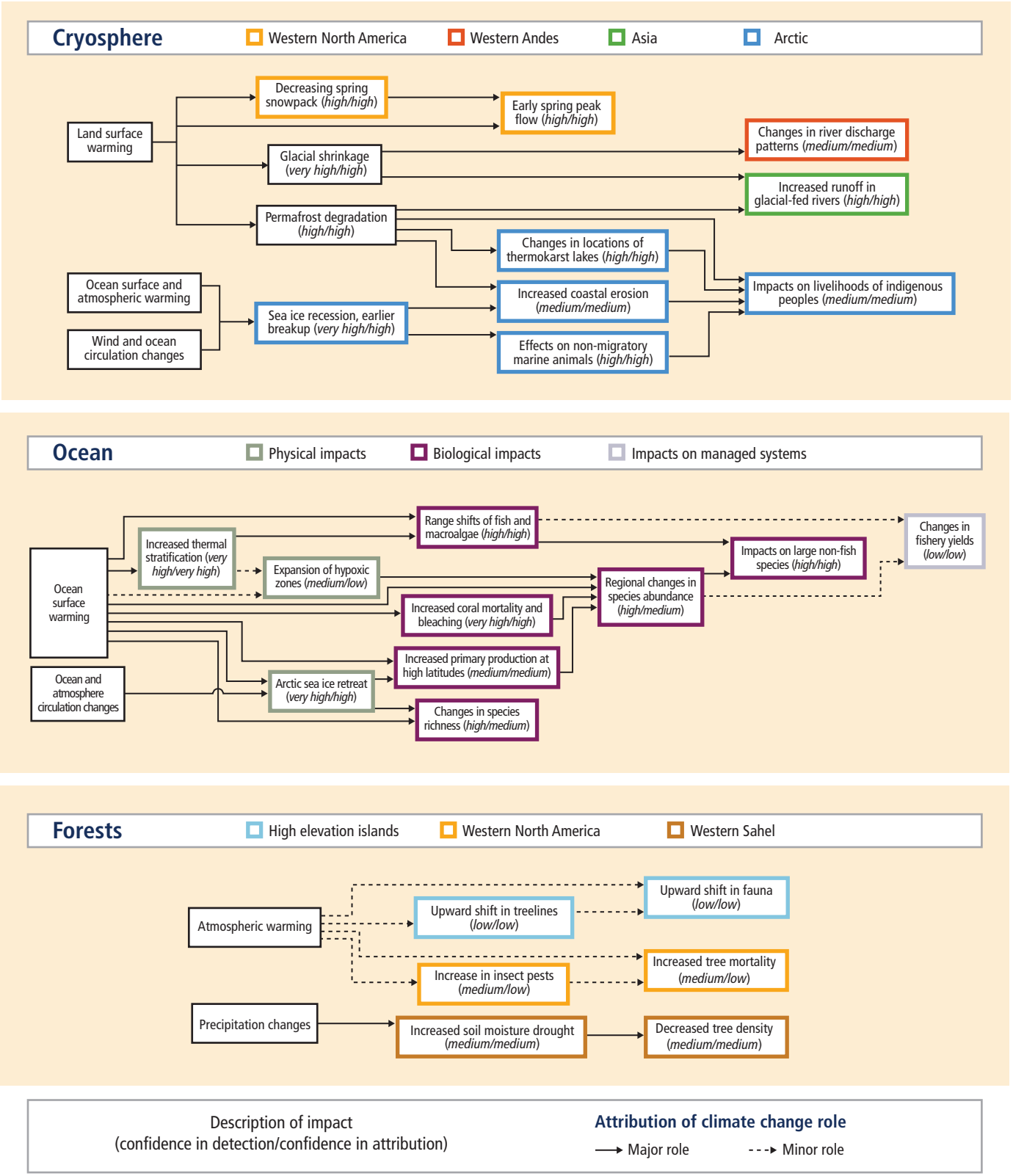


Figure 1.12 | Major systems where new evidence indicates interconnected, 'cascading' impacts from recent climate change through several natural and human subsystems. Bracketed text indicates confidence in the detection of a climate change effect and the attribution of observed impacts to climate change. The role of climate change can be major (solid arrow) or minor (dashed arrow). Initial evidence indicates that ocean acidification is following similar trends with respect to impact on human systems as ocean warming. *{WGII Figure 18-4}*

1.4 Extreme events

Changes in many extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events in a number of regions.

It is *very likely* that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is *likely* that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. It is *very likely* that human influence has contributed to the observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century. It is *likely* that human influence has more than doubled the probability of occurrence of heat waves in some locations. *{WGI SPM B.1, SPM D.3, Table SPM.1, FAQ 2.2, 2.6.1, 10.6}*

There is *medium confidence* that the observed warming has increased heat-related human mortality and decreased cold-related human mortality in some regions. Extreme heat events currently result in increases in mortality and morbidity in North America (*very high confidence*), and in Europe with impacts that vary according to people's age, location and socio-economic factors (*high confidence*). *{WGII SPM A-1, 11.4.1, Table 23-1, 26.6.1.2}*

There are *likely* more land regions where the number of heavy precipitation events has increased than where it has decreased. The frequency and intensity of heavy precipitation events has *likely* increased in North America and Europe. In other continents, *confidence* in trends is at most *medium.* It is *very likely* that global near-surface and tropospheric air specific humidity has increased since the 1970s. In land regions where observational coverage is sufficient for assessment, there is *medium confidence* that anthropogenic forcing has contributed to a global-scale intensification of heavy precipitation over the second half of the 20th century. *{WGI SPM B-1, 2.5.1, 2.5.4–2.5.5, 2.6.2, 10.6, Table SPM.1, FAQ 2.2, SREX Table 3-1, 3.2}*

There is *low confidence* that anthropogenic climate change has affected the frequency and magnitude of fluvial floods on a global scale. The strength of the evidence is limited mainly by a lack of long-term records from unmanaged catchments. Moreover, floods are strongly influenced by many human activities impacting catchments, making the attribution of detected changes to climate change difficult. However, recent detection of increasing trends in extreme precipitation and discharges in some catchments implies greater risks of flooding on a regional scale (*medium confidence*). Costs related to flood damage, worldwide, have been increasing since the 1970s, although this is partly due to the increasing exposure of people and assets. *{WGI 2.6.2, WGII 3.2.7, SREX SPM B}*

There is *low confidence* in observed global-scale trends in droughts, due to lack of direct observations, dependencies of inferred trends on the choice of the definition for drought, and due to geographical inconsistencies in drought trends. There is also *low confidence* in the attribution of changes in drought over global land areas since the mid-20th century, due to the same observational uncertainties and difficulties in distinguishing decadal scale variability in drought from long-term trends. *{WGI Table SPM.1, 2.6.2.3, 10.6, Figure 2.33, WGII 3.ES, 3.2.7}*

There is *low confidence* that long-term changes in tropical cyclone activity are robust, and there is *low confidence* in the attribution of global changes to any particular cause. However, it is *virtually certain* that intense tropical cyclone activity has increased in the North Atlantic since 1970. *{WGI Table SPM.1, 2.6.3, 10.6}*

It is *likely* that extreme sea levels (for example, as experienced in storm surges) have increased since 1970, being mainly the result of mean sea level rise. Due to a shortage of studies and the difficulty of distinguishing any such impacts from other modifications to coastal systems, limited evidence is available on the impacts of sea level rise. *{WGI 3.7.4–3.7.6, Figure 3.15, WGII 5.3.3.2, 18.3}*

Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability (*very high confidence*). Impacts of such climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, human morbidity and mortality and consequences for mental health and human well-being. For countries at all levels of development, these impacts are consistent with a significant lack of preparedness for current climate variability in some sectors. *{WGII SPM A-1, 3.2, 4.2-3, 8.1, 9.3, 10.7, 11.3, 11.7, 13.2, 14.1, 18.6, 22.2.3, 22.3, 23.3.1.2, 24.4.1, 25.6-8, 26.6-7, 30.5, Table 18-3, Table 23-1, Figure 26-2, Box 4-3, Box 4-4, Box 25-5, Box 25-6, Box 25-8, Box CC-CR}*

Direct and insured losses from weather-related disasters have increased substantially in recent decades, both globally and regionally. Increasing exposure of people and economic assets has been the major cause of long-term increases in economic losses from weather- and climate-related disasters (*high confidence*). *{WGII 10.7.3, SREX SPM B, 4.5.3.3}*

1.5 Exposure and vulnerability

The character and severity of impacts from climate change and extreme events emerge from risk that depends not only on climate-related hazards but also on exposure (people and assets at risk) and vulnerability (susceptibility to harm) of human and natural systems.

Exposure and vulnerability are influenced by a wide range of social, economic and cultural factors and processes that have been incompletely considered to date and that make quantitative assessments of their future trends difficult (*high confidence*). These factors include wealth and its distribution across society, demographics, migration, access to technology and information, employment patterns, the quality of adaptive responses, societal values, governance structures and institutions to resolve conflict. *{WGII SPM A-3, SREX SPM B}*

Differences in vulnerability and exposure arise from non-climatic factors and from multidimensional inequalities often produced by uneven development processes (*very high confidence*). These differences shape differential risks from climate change. People who are socially, economically, culturally, politically, institutionally or otherwise marginalized are especially vulnerable to climate change and also to some adaptation and mitigation responses (*medium evidence, high agreement*). This heightened vulnerability is rarely due to a single cause. Rather, it is the product of intersecting social processes that result in inequalities in socio-economic status and income, as well as in exposure. Such social processes include, for example, discrimination on the basis of gender, class, ethnicity, age and (dis)ability. *{WGII SPM A-1, Figure SPM.1, 8.1–8.2, 9.3–9.4, 10.9, 11.1, 11.3–11.5, 12.2–12.5, 13.1–13.3, 14.1–14.3, 18.4, 19.6, 23.5, 25.8, 26.6, 26.8, 28.4, Box CC-GC}*

Climate-related hazards exacerbate other stressors, often with negative outcomes for livelihoods, especially for people living in poverty (*high confidence*). Climate-related hazards affect poor people's lives directly through impacts on livelihoods, reductions in crop yields or the destruction of homes, and indirectly through, for example, increased food prices and food insecurity. Observed positive effects for poor and marginalized people, which are limited and often indirect, include examples such as diversification of social networks and of agricultural practices. *{WGII SPM A-1, 8.2–8.3, 9.3, 11.3, 13.1–13.3, 22.3, 24.4, 26.8}*

Violent conflict increases vulnerability to climate change (*medium evidence, high agreement*). Large-scale violent conflict harms assets that facilitate adaptation, including infrastructure, institutions, natural resources, social capital and livelihood opportunities. *{WGII SPM A-1, 12.5, 19.2, 19.6}*

1.6 Human responses to climate change: adaptation and mitigation

Adaptation and mitigation experience is accumulating across regions and scales, even while global anthropogenic greenhouse gas emissions have continued to increase.

Throughout history, people and societies have adjusted to and coped with climate, climate variability and extremes, with varying degrees of success. In today's changing climate, accumulating experience with adaptation and mitigation efforts can provide opportunities for learning and refinement (3, 4). *{WGII SPM A-2}*

Adaptation is becoming embedded in some planning processes, with more limited implementation of responses (*high confidence*). Engineered and technological options are commonly implemented adaptive responses, often integrated within existing programmes, such as disaster risk management and water management. There is increasing recognition of the value of social, institutional and ecosystem-based measures and of the extent of constraints to adaptation. *{WGII SPM A-2, 4.4, 5.5, 6.4, 8.3, 9.4, 11.7, 14.1, 14.3–14.4, 15.2–15.5, 17.2–17.3, 21.3, 21.5, 22.4, 23.7, 25.4, 26.8–26.9, 30.6, Box 25-1, Box 25-2, Box 25-9, Box CC-EA}*

Governments at various levels have begun to develop adaptation plans and policies and integrate climate change considerations into broader development plans. Examples of adaptation are now available from all regions of the world (see Topic 4 for details on adaptation options and policies to support their implementation). *{WGII SPM A-2, 22.4, 23.7, 24.4–24.6, 24.9, 25.4, 25.10, 26.7–26.9, 27.3, 28.2, 28.4, 29.3, 29.6, 30.6, Table 25-2, Table 29-3, Figure 29-1, Box 5-1, Box 23-3, Box 25-1, Box 25-2, Box 25-9, Box CC-TC}*

Global increases in anthropogenic emissions and climate impacts have occurred, even while mitigation activities have taken place in many parts of the world. Though various mitigation initiatives between the sub-national and global scales have been developed or implemented, a full assessment of their impact may be premature. *{WGIII SPM.3, SPM.5}*

2 Future Climate Changes, Risks and Impacts

Topic 2: Future Climate Changes, Risk and Impacts

Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks.

Topic 2 assesses projections of future climate change and the resulting risks and impacts. Factors that determine future climate change, including scenarios for future greenhouse gas (GHG) emissions, are outlined in Section 2.1. Descriptions of the methods and tools used to make projections of climate, impacts and risks, and their development since the IPCC Fourth Assessment Report (AR4), are provided in Boxes 2.1 to 2.3. Details of projected changes in the climate system, including the associated uncertainty and the degree of expert confidence in the projections are provided in Section 2.2. The future impacts of climate change on natural and human systems and associated risks are assessed in Section 2.3. Topic 2 concludes with an assessment of irreversible changes, abrupt changes and changes beyond 2100 in Section 2.4.

2.1 Key drivers of future climate and the basis on which projections are made

Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. Projections of greenhouse gas emissions vary over a wide range, depending on both socio-economic development and climate policy.

Climate models are mathematical representations of processes important in the Earth's climate system. Results from a hierarchy of climate models are considered in this report; ranging from simple idealized models, to models of intermediate complexity, to comprehensive General Circulation Models (GCMs), including Earth System Models (ESMs) that also simulate the carbon cycle. The GCMs simulate many climate aspects, including the temperature of the atmosphere and the oceans, precipitation, winds, clouds, ocean currents and sea-ice extent. The models are extensively tested against historical observations (Box 2.1). *{WGI 1.5.2, 9.1.2, 9.2, 9.8.1}*

In order to obtain climate change projections, the climate models use information described in scenarios of GHG and air pollutant emissions and land use patterns. Scenarios are generated by a range of approaches, from simple idealised experiments to Integrated Assessment Models (IAMs, see Glossary). Key factors driving changes in anthropogenic GHG emissions are economic and population growth, lifestyle and behavioural changes, associated changes in energy use and land use, technology and climate policy, which are fundamentally uncertain. *{WGI 11.3, 12.4, WGIII 5, 6, 6.1}*

The standard set of scenarios used in the AR5 is called Representative Concentration Pathways (RCPs, Box 2.2). *{WGI Box SPM.1}*

Box 2.1 | Advances, Confidence and Uncertainty in Modelling the Earth's Climate System

Improvements in climate models since the IPCC Fourth Assessment Report (AR4) are evident in simulations of continental-scale surface temperature, large-scale precipitation, the monsoon, Arctic sea ice, ocean heat content, some extreme events, the carbon cycle, atmospheric chemistry and aerosols, the effects of stratospheric ozone and the El Niño-Southern Oscillation. Climate models reproduce the observed continental-scale surface temperature patterns and multi-decadal trends, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions (*very high confidence*). The simulation of large-scale patterns of precipitation has improved somewhat since the AR4, although models continue to perform less well for precipitation than for surface temperature. *Confidence* in the representation of processes involving clouds and aerosols remains *low*. *{WGI SPM D.1, 7.2.3,* 7.3.3, *7.6.2, 9.4, 9.5, 9.8, 10.3.1}*

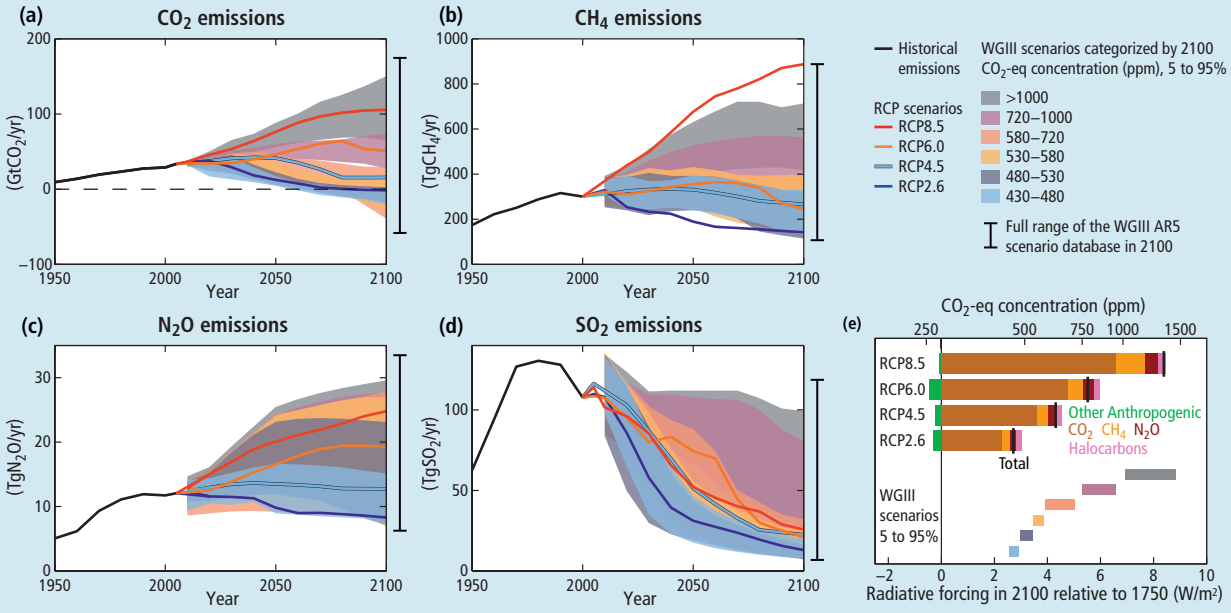
The ability to simulate ocean thermal expansion, glaciers and ice sheets, and thus sea level, has improved since the AR4, but significant challenges remain in representing the dynamics of the Greenland and Antarctic ice sheets. This, together with advances in scientific understanding and capability, has resulted in improved sea level projections in this report, compared with the AR4. *{WGI SPM E.6, 9.1.3, 9.2, 9.4.2, 9.6, 9.8, 13.1, 13.4, 13.5}*

There is overall consistency between the projections from climate models in AR4 and AR5 for large-scale patterns of change and the magnitude of the uncertainty has not changed significantly, but new experiments and studies have led to a more complete and rigorous characterization of the uncertainty in long-term projections. *{WGI 12.4}*

Box 2.2 | The Representative Concentration Pathways

The Representative Concentration Pathways (RCPs) describe four different 21st century pathways of greenhouse gas (GHG) emissions and atmospheric concentrations, air pollutant emissions and land use. The RCPs have been developed using Integrated Assessment Models (IAMs) as input to a wide range of climate model simulations to project their consequences for the climate system. These climate projections, in turn, are used for impacts and adaptation assessment. The RCPs are consistent with the wide range of scenarios in the mitigation literature assessed by WGIII[28]. The scenarios are used to assess the costs associated with emission reductions consistent with particular concentration pathways. The RCPs represent the range of GHG emissions in the wider literature well (Box 2.2, Figure 1); they include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and one scenario with very high GHG emissions (RCP8.5). Scenarios without additional efforts to constrain emissions ('baseline scenarios') lead to pathways ranging between RCP6.0 and RCP8.5. RCP2.6 is representative of a scenario that aims to keep global warming *likely* below 2°C above pre-industrial temperatures. The majority of models indicate that scenarios meeting forcing levels similar to RCP2.6 are characterized by substantial net negative emissions[29] by 2100, on average around 2 $GtCO_2$/yr. The land use scenarios of RCPs, together, show a wide range of possible futures, ranging from a net reforestation to further deforestation, consistent with projections in the full scenario literature. For air pollutants such as sulfur dioxide (SO_2), the RCP scenarios assume a consistent decrease in emissions as a consequence of assumed air pollution control and GHG mitigation policy (Box 2.2, Figure 1). Importantly, these future scenarios do not account for possible changes in natural forcings (e.g., volcanic eruptions) (see Box 1.1). *{WGI Box SPM.1, 6.4, 8.5.3, 12.3, Annex II, WGII 19, 21, WGIII 6.3.2, 6.3.6}*

The RCPs cover a wider range than the scenarios from the Special Report on Emissions Scenarios (SRES) used in previous assessments, as they also represent scenarios with climate policy. In terms of overall forcing, RCP8.5 is broadly comparable to the SRES A2/A1FI scenario, RCP6.0 to B2 and RCP4.5 to B1. For RCP2.6, there is no equivalent scenario in SRES. As a result, the differences in the magnitude of AR4 and AR5 climate projections are largely due to the inclusion of the wider range of emissions assessed. *{WGI TS Box TS.6, 12.4.9}*



Box 2.2, Figure 1 | Emission scenarios and the resulting radiative forcing levels for the Representative Concentration Pathways (RCPs, lines) and the associated scenarios categories used in WGIII (coloured areas, see Table 3.1). Panels a to d show the emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and sulfur dioxide (SO_2). Panel e shows future radiative forcing levels for the RCPs calculated using the simple carbon cycle climate model, Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC), for the RCPs (per forcing agent) and for the WGIII scenario categories (total) *{WGI 8.2.2, 8.5.3, Figure 8.2, Annex II, WGIII Table SPM.1, Table 6.3}*. The WGIII scenario categories summarize the wide range of emission scenarios published in the scientific literature and are defined based on total CO_2-equivalent concentrations (in ppm) in 2100 (Table 3.1). The vertical lines to the right of the panels (panel a–d) indicate the full range of the WGIII AR5 scenario database.

[28] Roughly 300 baseline scenarios and 900 mitigation scenarios are categorized by CO_2-equivalent concentration (CO_2-eq) by 2100. The CO_2-eq includes the forcing due to all GHGs (including halogenated gases and tropospheric ozone), aerosols and albedo change (see Glossary).

[29] Net negative emissions can be achieved when more GHGs are sequestered than are released into the atmosphere (e.g., by using bio-energy in combination with carbon dioxide capture and storage).

The methods used to estimate future impacts and risks resulting from climate change are described in Box 2.3. Modelled future impacts assessed in this report are generally based on climate-model projections using the RCPs, and in some cases, the older Special Report on Emissions Scenarios (SRES). *{WGI Box SPM.1, WGII 1.1, 1.3, 2.2–2.3, 19.6, 20.2, 21.3, 21.5, 26.2, Box CC-RC}*

Risk of climate-related impacts results from the interaction between climate-related hazards (including hazardous events and trends) and the vulnerability and exposure of human and natural systems. Alternative development paths influence risk by changing the likelihood of climatic events and trends, through their effects on GHGs, pollutants and land use, and by altering vulnerability and exposure. *{WGII SPM, 19.2.4, Figure 19-1, Box 19-2}*

Experiments, observations and models used to estimate future impacts and risks have improved since the AR4, with increasing understanding across sectors and regions. For example, an improved knowledge base has enabled expanded assessment of risks for human security and livelihoods and for the oceans. For some aspects of climate change and climate change impacts, uncertainty about future outcomes has narrowed. For others, uncertainty will persist. Some of the persistent uncertainties are grounded in the mechanisms that control the magnitude and pace of climate change. Others emerge from potentially complex interactions between the changing climate and the underlying vulnerability and exposure of people, societies and ecosystems. The combination of persistent uncertainty in key mechanisms plus the prospect of complex interactions motivates a focus on risk in this report. Because risk involves both probability and consequence, it is important to consider the full range of possible outcomes, including low-probability, high-consequence impacts that are difficult to simulate. *{WGII 2.1–2.4, 3.6, 4.3, 11.3, 12.6, 19.2, 19.6, 21.3–21.5, 22.4, 25.3–25.4, 25.11, 26.2}*

2.2 Projected changes in the climate system

Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is *very likely* that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise.

The projected changes in Section 2.2 are for 2081–2100 relative to 1986–2005, unless otherwise indicated.

2.2.1 Air temperature

The global mean surface temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four RCPs, and will *likely* be in the range 0.3°C to 0.7°C (*medium confidence*)[30]. This range assumes no major volcanic eruptions or changes in some natural sources (e.g., methane (CH_4) and nitrous oxide (N_2O)), or unexpected changes in total solar irradiance. Future climate will depend on

Box 2.3 | Models and Methods for Estimating Climate Change Risks, Vulnerability and Impacts

Future climate-related risks, vulnerabilities and impacts are estimated in the AR5 through experiments, analogies and models, as in previous assessments. 'Experiments' involve deliberately changing one or more climate-system factors affecting a subject of interest to reflect anticipated future conditions, while holding the other factors affecting the subject constant. 'Analogies' make use of existing variations and are used when controlled experiments are impractical due to ethical constraints, the large area or long time required or high system complexity. Two types of analogies are used in projections of climate and impacts. Spatial analogies identify another part of the world currently experiencing similar conditions to those anticipated to be experienced in the future. Temporal analogies use changes in the past, sometimes inferred from paleo-ecological data, to make inferences about changes in the future. 'Models' are typically numerical simulations of real-world systems, calibrated and validated using observations from experiments or analogies, and then run using input data representing future climate. Models can also include largely descriptive narratives of possible futures, such as those used in scenario construction. Quantitative and descriptive models are often used together. Impacts are modelled, among other things, for water resources, biodiversity and ecosystem services on land, inland waters, the oceans and ice bodies, as well as for urban infrastructure, agricultural productivity, health, economic growth and poverty. *{WGII 2.2.1, 2.4.2, 3.4.1, 4.2.2, 5.4.1, 6.5, 7.3.1, 11.3.6, 13.2.2}*

Risks are evaluated based on the interaction of projected changes in the Earth system with the many dimensions of vulnerability in societies and ecosystems. The data are seldom sufficient to allow direct estimation of probabilities of a given outcome; therefore, expert judgment using specific criteria (large magnitude, high probability or irreversibility of impacts; timing of impacts; persistent vulnerability or exposure contributing to risks; or limited potential to reduce risks through adaptation or mitigation) is used to integrate the diverse information sources relating to the severity of consequences and the likelihood of occurrence into a risk evaluation, considering exposure and vulnerability in the context of specific hazards. *{WGII 11.3, 19.2, 21.1, 21.3–21.5, 25.3–25.4, 25.11, 26.2}*

[30] The 1986–2005 period was approximately 0.61 [0.55 to 0.67] °C warmer than the period 1850–1900. *{WGI SPM E, 2.4.3}*

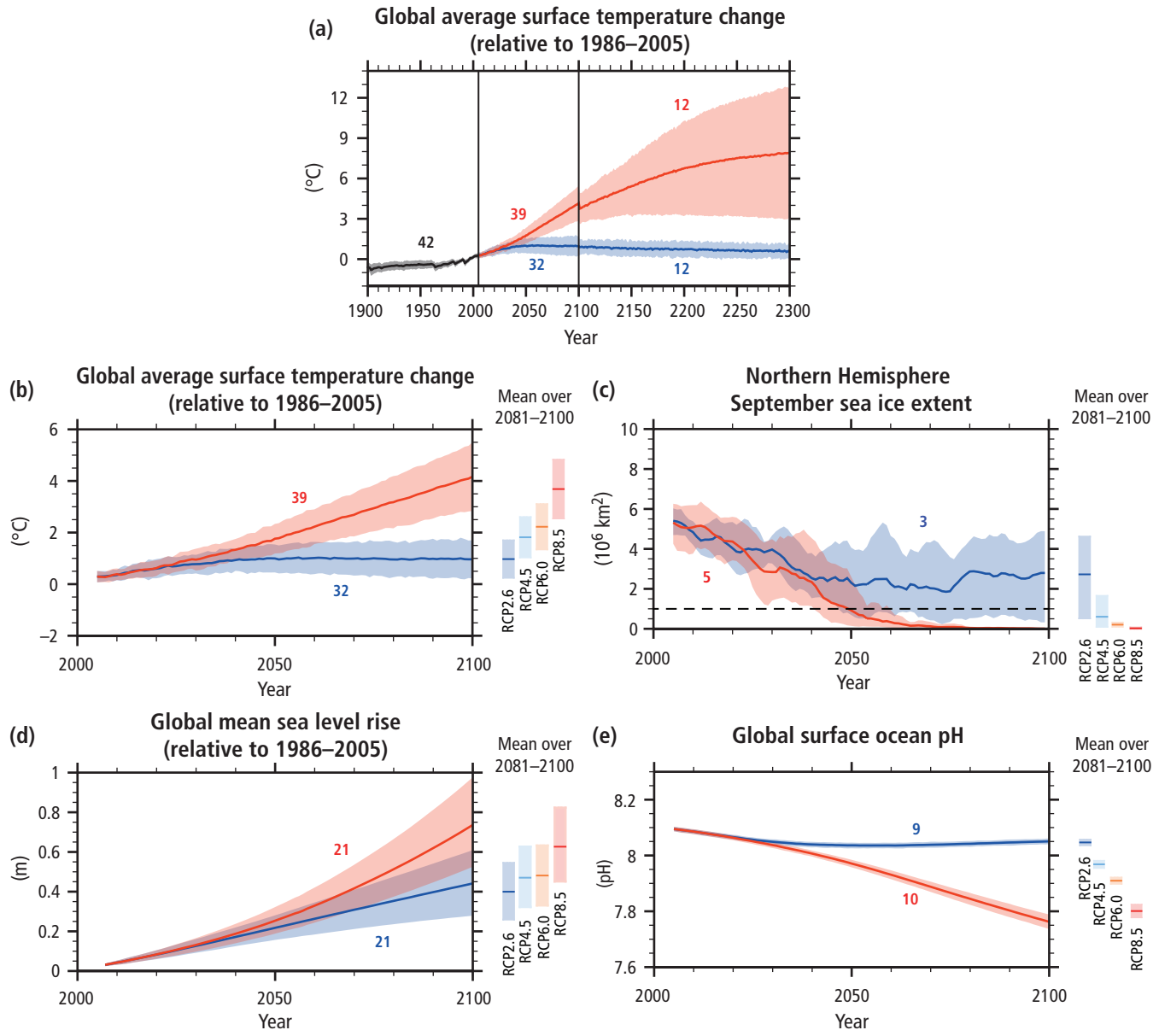


Figure 2.1 | (a) Time series of global annual change in mean surface temperature for the 1900–2300 period (relative to 1986–2005) from Coupled Model Intercomparison Project Phase 5 (CMIP5) concentration-driven experiments. Projections are shown for the multi-model mean (solid lines) and the 5 to 95% range across the distribution of individual models (shading). Grey lines and shading represent the CMIP5 historical simulations. Discontinuities at 2100 are due to different numbers of models performing the extension runs beyond the 21st century and have no physical meaning. **(b)** Same as (a) but for the 2006–2100 period (relative to 1986–2005). **(c)** Change in Northern Hemisphere September sea-ice extent (5 year running mean). The dashed line represents nearly ice-free conditions (i.e., when September sea-ice extent is less than 10^6 km^2 for at least five consecutive years). **(d)** Change in global mean sea level. **(e)** Change in ocean surface pH. For all panels, time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). The number of CMIP5 models used to calculate the multi-model mean is indicated. The mean and associated uncertainties averaged over the 2081–2100 period are given for all RCP scenarios as coloured vertical bars on the right hand side of panels (b) to (e). For sea-ice extent (c), the projected mean and uncertainty (minimum–maximum range) is only given for the subset of models that most closely reproduce the climatological mean state and the 1979–2012 trend in the Arctic sea ice. For sea level (d), based on current understanding (from observations, physical understanding and modelling), only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. However, there is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century. *{WGI Figure SPM.7, Figure SPM.9, Figure 12.5, 6.4.4, 12.4.1, 13.4.4, 13.5.1}*

committed warming caused by past anthropogenic emissions, as well as future anthropogenic emissions and natural climate variability. By the mid-21st century, the magnitude of the projected climate change is substantially affected by the choice of emissions scenarios. Climate change continues to diverge among the scenarios through to 2100 and beyond (Table 2.1, Figure 2.1). The ranges provided for particular RCPs (Table 2.1), and those given below in Section 2.2, primarily arise from differences in the sensitivity of climate models to the imposed forcing. *{WGI SPM E.1, 11.3.2, 12.4.1}*

Table 2.1 | Projected change in global mean surface temperature and global mean sea level rise for the mid- and late 21st century, relative to the 1986–2005 period. *{WGI Table SPM.2, 12.4.1, 13.5.1, Table 12.2, Table 13.5}*

		2046–2065		2081–2100	
	Scenario	**Mean**	***Likely* range [c]**	**Mean**	***Likely* range [c]**
Global Mean Surface Temperature Change (°C) [a]	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	Scenario	**Mean**	***Likely* range [d]**	**Mean**	***Likely* range [d]**
Global Mean Sea Level Rise (m) [b]	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Notes:

[a] Based on the Coupled Model Intercomparison Project Phase 5 (CMIP5) ensemble; changes calculated with respect to the 1986–2005 period. Using Hadley Centre Climatic Research Unit Gridded Surface Temperature Data Set 4 (HadCRUT4) and its uncertainty estimate (5 to 95% confidence interval), the observed warming from 1850–1900 to the reference period 1986–2005 is 0.61 [0.55 to 0.67] °C. *Likely* ranges have not been assessed here with respect to earlier reference periods because methods are not generally available in the literature for combining the uncertainties in models and observations. Adding projected and observed changes does not account for potential effects of model biases compared to observations, and for natural internal variability during the observational reference period. *{WGI 2.4.3, 11.2.2, 12.4.1, Table 12.2, Table 12.3}*

[b] Based on 21 CMIP5 models; changes calculated with respect to the 1986–2005 period. Based on current understanding (from observations, physical understanding and modelling), only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. There is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century.

[c] Calculated from projections as 5 to 95% model ranges. These ranges are then assessed to be *likely* ranges after accounting for additional uncertainties or different levels of confidence in models. For projections of global mean surface temperature change in 2046–2065, *confidence* is *medium*, because the relative importance of natural internal variability, and uncertainty in non-greenhouse gas forcing and response, are larger than for the 2081–2100 period. The *likely* ranges for 2046–2065 do not take into account the possible influence of factors that lead to the assessed range for near term (2016–2035) change in global mean surface temperature that is lower than the 5 to 95% model range, because the influence of these factors on longer term projections has not been quantified due to insufficient scientific understanding. *{WGI 11.3.1}*

[d] Calculated from projections as 5 to 95% model ranges. These ranges are then assessed to be *likely* ranges after accounting for additional uncertainties or different levels of confidence in models. For projections of global mean sea level rise *confidence* is *medium* for both time horizons.

Relative to 1850–1900, global surface temperature change for the end of the 21st century (2081–2100) is projected to *likely* exceed 1.5°C for RCP4.5, RCP6.0 and RCP8.5 (*high confidence*). Warming is *likely* to exceed 2°C for RCP6.0 and RCP8.5 (*high confidence*), *more likely than not* to exceed 2°C for RCP4.5 (*medium confidence*), but *unlikely* to exceed 2°C for RCP2.6 (*medium confidence*). *{WGI SPM E.1, 12.4.1, Table 12.3}*

The Arctic region will continue to warm more rapidly than the global mean (Figure 2.2) (*very high confidence*). The mean warming over land will be larger than over the ocean (*very high confidence*) and larger than global average warming (Figure 2.2). *{WGI SPM E.1, 11.3.2, 12.4.3, 14.8.2}*

It is *virtually certain* that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases. It is *very likely* that heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur. *{WGI SPM E.1, 12.4.3}*

2.2.2 Water cycle

Changes in precipitation in a warming world will not be uniform. The high latitudes and the equatorial Pacific are *likely* to experience an increase in annual mean precipitation by the end of this century under the RCP8.5 scenario. In many mid-latitude and subtropical dry regions, mean precipitation will *likely* decrease, while in many mid-latitude wet regions, mean precipitation will *likely* increase under the RCP8.5 scenario (Figure 2.2). *{WGI SPM E.2, 7.6.2, 12.4.5, 14.3.1, 14.3.5}*

Extreme precipitation events over most mid-latitude land masses and over wet tropical regions will *very likely* become more intense and more frequent as global mean surface temperature increases. *{WGI SPM E.2, 7.6.2, 12.4.5}*

Globally, in all RCPs, it is *likely* that the area encompassed by monsoon systems will increase and monsoon precipitation is *likely* to intensify and El Niño-Southern Oscillation (ENSO) related precipitation variability on regional scales will *likely* intensify. *{WGI SPM E.2, 14.2, 14.4}*

2.2.3 Ocean, cryosphere and sea level

The global ocean will continue to warm during the 21st century. The strongest ocean warming is projected for the surface in tropical and Northern Hemisphere subtropical regions. At greater depth the warming will be most pronounced in the Southern Ocean (*high confidence*). *{WGI SPM E.4, 6.4.5, 12.4.7}*

It is *very likely* that the Atlantic Meridional Overturning Circulation (AMOC) will weaken over the 21st century, with best estimates and model ranges for the reduction of 11% (1 to 24%) for

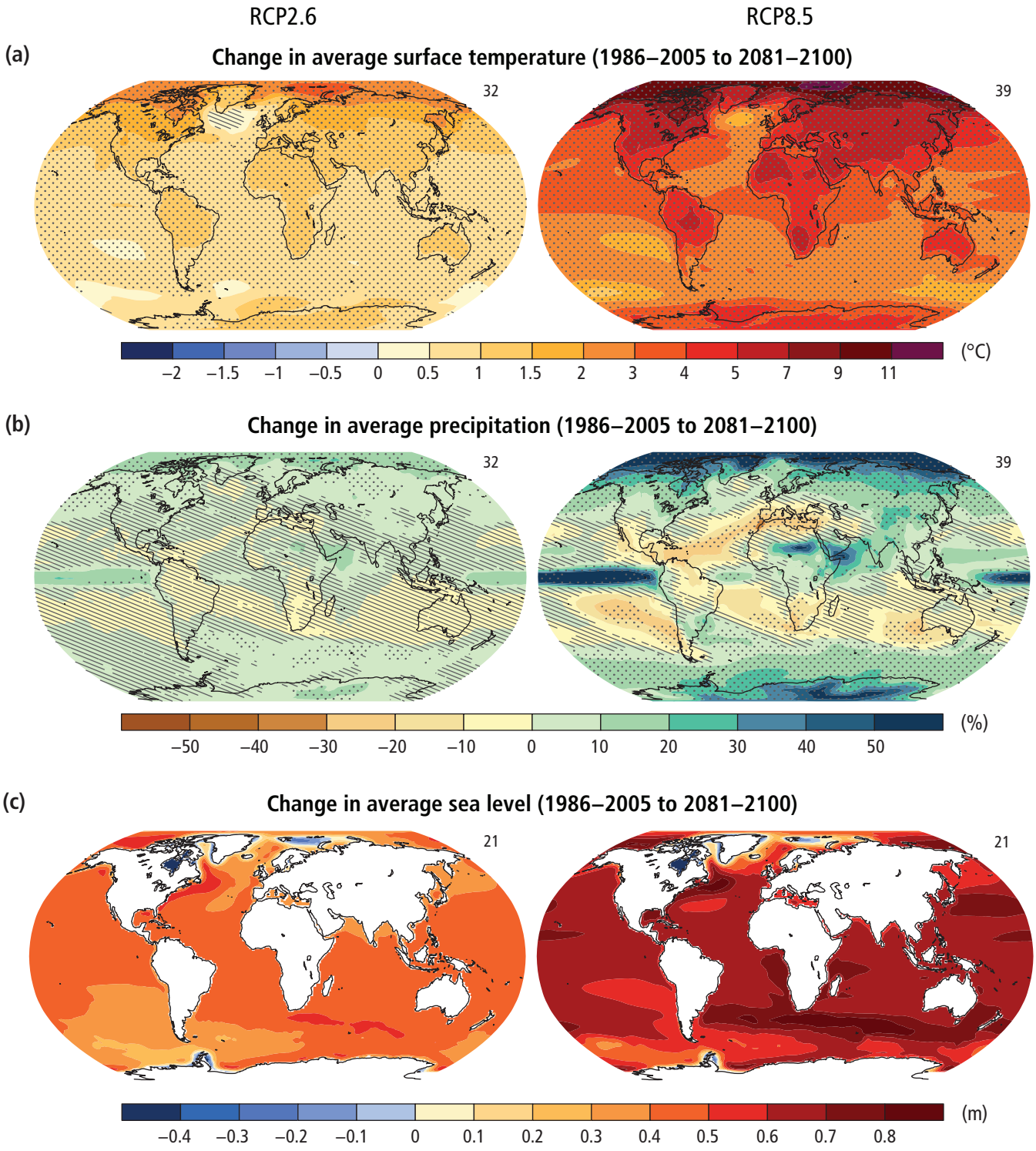


Figure 2.2 | Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model mean projections (i.e., the average of the model projections available) for the 2081–2100 period under the RCP2.6 (left) and RCP8.5 (right) scenarios for **(a)** change in annual mean surface temperature and **(b)** change in annual mean precipitation, in percentages, and **(c)** change in average sea level. Changes are shown relative to the 1986–2005 period. The number of CMIP5 models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Stippling (dots) on (a) and (b) indicates regions where the projected change is large compared to natural internal variability (i.e., greater than two standard deviations of internal variability in 20-year means) and where 90% of the models agree on the sign of change. Hatching (diagonal lines) on (a) and (b) shows regions where the projected change is less than one standard deviation of natural internal variability in 20-year means. *{WGI Figure SPM.8, Figure 13.20, Box 12.1}*

the RCP2.6 scenario, 34% (12 to 54%) for the RCP8.5. Nevertheless, it is *very unlikely* that the AMOC will undergo an abrupt transition or collapse in the 21st century. *{WGI SPM E.4, 12.4.7.2}*

Year-round reductions in Arctic sea ice are projected for all RCP scenarios. The subset of models that most closely reproduce the observations[31] project that a nearly ice-free Arctic Ocean[32] in September is *likely* for RCP8.5 before mid-century (*medium confidence*) (Figure 2.1). In the Antarctic, a decrease in sea ice extent and volume is projected with *low confidence*. *{WGI SPM E.5, 12.4.6.1}*

The area of Northern Hemisphere spring snow cover is *likely* to decrease by 7% for RCP2.6 and by 25% in RCP8.5 by the end of the 21st century for the multi-model average (*medium confidence*). *{WGI SPM E.5, 12.4.6}*

It is *virtually certain* that near-surface permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases. The area of permafrost near the surface (upper 3.5 m) is *likely* to decrease by 37% (RCP2.6) to 81% (RCP8.5) for the multi-model average (*medium confidence*). *{WGI SPM E.5, 12.4.6}*

The global glacier volume, excluding glaciers on the periphery of Antarctica (and excluding the Greenland and Antarctic ice sheets), is projected to decrease by 15 to 55% for RCP2.6 and by 35 to 85% for RCP8.5 (*medium confidence*). *{WGI SPM E.5, 13.4.2, 13.5.1}*

Global mean sea level will continue to rise during the 21st century (Table 2.1, Figure 2.1). There has been significant improvement in understanding and projection of sea level change since the AR4. Under all RCP scenarios, the rate of sea level rise will *very likely* exceed the observed rate of 2.0 [1.7–2.3] mm/yr during 1971–2010, with the rate of rise for RCP8.5 during 2081–2100 of 8 to 16 mm/yr (*medium confidence*). *{WGI SPM B4, SPM E.6, 13.5.1}*

Sea level rise will not be uniform across regions. By the end of the 21st century, it is *very likely* that sea level will rise in more than about 95% of the ocean area. Sea level rise depends on the pathway of CO_2 emissions, not only on the cumulative total; reducing emissions earlier rather than later, for the same cumulative total, leads to a larger mitigation of sea level rise. About 70% of the coastlines worldwide are projected to experience sea level change within ±20% of the global mean (Figure 2.2). It is *very likely* that there will be a significant increase in the occurrence of future sea level extremes in some regions by 2100. *{WGI SPM E.6, TS 5.7.1, 12.4.1, 13.4.1, 13.5.1, 13.6.5, 13.7.2, Table 13.5}*

2.2.4 Carbon cycle and biogeochemistry

Ocean uptake of anthropogenic CO_2 will continue under all four RCPs through to 2100, with higher uptake for higher concentration pathways (*very high confidence*). The future evolution of the land carbon uptake is less certain. A majority of models projects a continued land carbon uptake under all RCPs, but some models simulate a land carbon loss due to the combined effect of climate change and land use change. *{WGI SPM E.7, 6.4.2, 6.4.3}*

Based on Earth System Models, there is *high confidence* that the feedback between climate change and the carbon cycle will amplify global warming. Climate change will partially offset increases in land and ocean carbon sinks caused by rising atmospheric CO_2. As a result more of the emitted anthropogenic CO_2 will remain in the atmosphere, reinforcing the warming. *{WGI SPM E.7, 6.4.2, 6.4.3}*

Earth System Models project a global increase in ocean acidification for all RCP scenarios by the end of the 21st century, with a slow recovery after mid-century under RCP2.6. The decrease in surface ocean pH is in the range of 0.06 to 0.07 (15 to 17% increase in acidity) for RCP2.6, 0.14 to 0.15 (38 to 41%) for RCP4.5, 0.20 to 0.21 (58 to 62%) for RCP6.0, and 0.30 to 0.32 (100 to 109%) for RCP8.5 (Figure 2.1). *{WGI SPM E.7, 6.4.4}*

It is *very likely* that the dissolved oxygen content of the ocean will decrease by a few percent during the 21st century in response to surface warming, predominantly in the subsurface mid-latitude oceans. There is no consensus on the future volume of low oxygen waters in the open ocean because of large uncertainties in potential biogeochemical effects and in the evolution of tropical ocean dynamics. *{WGI TS 5.6, 6.4.5, WGII TS B-2, 6.1}*

2.2.5 Climate system responses

Climate system properties that determine the response to external forcing have been estimated both from climate models and from analysis of past and recent climate change. The equilibrium climate sensitivity (ECS)[33] is *likely* in the range 1.5°C to 4.5°C, *extremely unlikely* less than 1°C, and *very unlikely* greater than 6°C. *{WGI SPM D.2, TS TFE.6, 10.8.1, 10.8.2, 12.5.4, Box 12.2}*

Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. Multiple lines of evidence indicate a strong and consistent near-linear relationship across all scenarios considered between net cumulative CO_2 emissions (including the impact of CO_2 removal) and projected global temperature change to the year 2100 (Figure 2.3). Past emissions and observed warming support this relationship within uncertainties. Any given level of warming is associated with a range of cumulative CO_2 emissions (depending on non-CO_2 drivers), and therefore, for example, higher emissions in earlier decades imply lower emissions later. *{WGI SPM E.8, TS TFE.8, 12.5.4}*

The global mean peak surface temperature change per trillion tonnes of carbon (1000 GtC) emitted as CO_2 is *likely* in the range of 0.8°C to 2.5°C. This quantity, called the transient climate response to cumulative carbon emissions (TCRE), is supported by both modelling and observational evidence and applies to cumulative emissions up to about 2000 GtC. *{WGI SPM D.2, TS TFE.6, 12.5.4, Box 12.2}*

[31] Climatological mean state and the 1979–2012 trend in Arctic sea-ice extent.

[32] When sea-ice extent is less than one million km² for at least five consecutive years.

[33] Defined as the equilibrium global average surface warming following a doubling of CO_2 concentration (relative to pre-industrial).

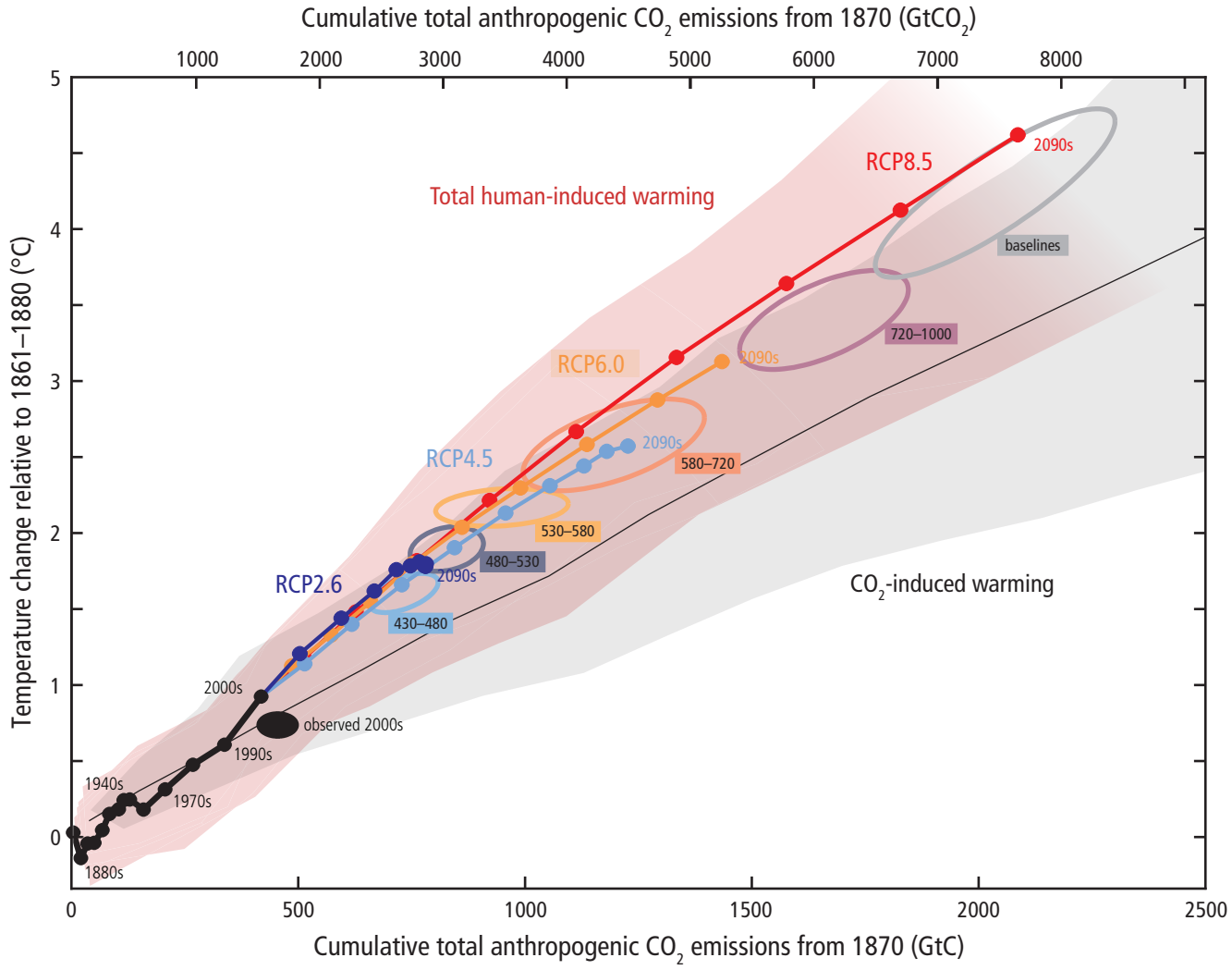


Figure 2.3 | Global mean surface temperature increase as a function of cumulative total global carbon dioxide (CO_2) emissions from various lines of evidence. Multi-model results from a hierarchy of climate carbon-cycle models for each Representative Concentration Pathway (RCP) until 2100 are shown (coloured lines). Model results over the historical period (1860 to 2010) are indicated in black. The coloured plume illustrates the multi-model spread over the four RCP scenarios and fades with the decreasing number of available models in RCP8.5. Dots indicate decadal averages, with selected decades labelled. Ellipses show total anthropogenic warming in 2100 versus cumulative CO_2 emissions from 1870 to 2100 from a simple climate model (median climate response) under the scenario categories used in WGIII. Temperature values are always given relative to the 1861–1880 period, and emissions are cumulative since 1870. Black filled ellipse shows observed emissions to 2005 and observed temperatures in the decade 2000–2009 with associated uncertainties. *{WGI SPM E.8, TS TFE.8, Figure 1, TS.SM.10, 12.5.4, Figure 12.45, WGIII Table SPM.1, Table 6.3}*

Warming caused by CO_2 emissions is effectively irreversible over multi-century timescales unless measures are taken to remove CO_2 from the atmosphere. Ensuring CO_2-induced warming remains *likely* less than 2°C requires cumulative CO_2 emissions from all anthropogenic sources to remain below about 3650 $GtCO_2$ (1000 GtC), over half of which were already emitted by 2011. *{WGI SPM E.8, TS TFE.8, 12.5.2, 12.5.3, 12.5.4}*

Multi-model results show that limiting total human-induced warming (accounting for both CO_2 and other human influences on climate) to less than 2°C relative to the period 1861–1880 with a probability of >66% would require total CO_2 emissions from all anthropogenic sources since 1870 to be limited to about 2900 $GtCO_2$ when accounting for non-CO_2 forcing as in the RCP2.6 scenario, with a range of 2550 to 3150 $GtCO_2$ arising from variations in non-CO_2 climate drivers across the scenarios considered by WGIII (Table 2.2). About 1900 [1650 to 2150] $GtCO_2$ were emitted by 2011, leaving about 1000 $GtCO_2$ to be consistent with this temperature goal. Estimated total fossil carbon reserves exceed this remaining amount by a factor of 4 to 7, with resources much larger still. *{WGI SPM E.8, TS TFE.8, Figure 1, TS.SM.10, 12.5.4, Figure 12.45, WGIII Table SPM.1, Table 6.3, Table 7.2}*

Table 2.2 | Cumulative carbon dioxide (CO_2) emission consistent with limiting warming to less than stated temperature limits at different levels of probability, based on different lines of evidence. *{WGI 12.5.4, WGIII 6}*

Cumulative CO_2 emissions from 1870 in $GtCO_2$									
Net anthropogenic warming [a]	<1.5°C			<2°C			<3°C		
Fraction of simulations meeting goal [b]	66%	50%	33%	66%	50%	33%	66%	50%	33%
Complex models, RCP scenarios only [c]	2250	2250	2550	2900	3000	3300	4200	4500	4850
Simple model, WGIII scenarios [d]	No data	2300 to 2350	2400 to 2950	2550 to 3150	2900 to 3200	2950 to 3800	n.a. [e]	4150 to 5750	5250 to 6000
Cumulative CO_2 emissions from 2011 in $GtCO_2$									
Complex models, RCP scenarios only [c]	400	550	850	1000	1300	1500	2400	2800	3250
Simple model, WGIII scenarios [d]	No data	550 to 600	600 to 1150	750 to 1400	1150 to 1400	1150 to 2050	n.a. [e]	2350 to 4000	3500 to 4250
Total fossil carbon available in 2011 [f]: 3670 to 7100 $GtCO_2$ (reserves) and 31300 to 50050 $GtCO_2$ (resources)									

Notes:

[a] Warming due to CO_2 and non-CO_2 drivers. Temperature values are given relative to the 1861–1880 base period.

[b] Note that the 66% range in this table should not be equated to the likelihood statements in Table SPM.1 and Table 3.1 and WGIII Table SPM.1. The assessment in these latter tables is not only based on the probabilities calculated for the full ensemble of scenarios in WGIII using a single climate model, but also the assessment in WGI of the uncertainty of the temperature projections not covered by climate models.

[c] Cumulative CO_2 emissions at the time the temperature threshold is exceeded that are required for 66%, 50% or 33% of the Coupled Model Intercomparison Project Phase 5 (CMIP5) complex models Earth System Model (ESM) and Earth System Models of Intermediate Complexity (EMIC) simulations, assuming non-CO_2 forcing follows the RCP8.5 scenario. Similar cumulative emissions are implied by other RCP scenarios. For most scenario–threshold combinations, emissions and warming continue after the threshold is exceeded. Nevertheless, because of the cumulative nature of CO_2 emissions, these figures provide an indication of the cumulative CO_2 emissions implied by the CMIP5 model simulations under RCP-like scenarios. Values are rounded to the nearest 50.

[d] Cumulative CO_2 emissions at the time of peak warming from WGIII scenarios for which a fraction of greater than 66% (66 to 100%), greater than 50% (50 to 66%) or greater than 33% (33 to 50%) of climate simulations keep global mean temperature increase to below the stated threshold. Ranges indicate the variation in cumulative CO_2 emissions arising from differences in non-CO_2 drivers across the WGIII scenarios. The fraction of climate simulations for each scenario is derived from a 600-member parameter ensemble of a simple carbon-cycle climate model, Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC), in a probabilistic mode. Parameter and scenario uncertainty are explored in this ensemble. Structural uncertainties cannot be explored with a single model set-up. Ranges show the impact of scenario uncertainty, with 80% of scenarios giving cumulative CO_2 emissions within the stated range for the given fraction of simulations. Simple model estimates are constrained by observed changes over the past century, do not account for uncertainty in model structure and may omit some feedback processes: they are hence slightly higher than the CMIP5 complex models estimates. Values are rounded to the nearest 50.

[e] The numerical results for the cumulative CO_2 emissions for staying below 3°C with greater than 66% (66 to 100%) is greatly influenced by a large number of scenarios that would also meet the 2°C objective and therefore not comparable with numbers provided for the other temperature threshold.

[f] Reserves are quantities able to be recovered under existing economic and operating conditions; resources are those where economic extraction is potentially feasible. *{WGIII Table 7.2}*

2.3 Future risks and impacts caused by a changing climate

Climate change will amplify existing risks and create new risks for natural and human systems. Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development. Increasing magnitudes of warming increase the likelihood of severe, pervasive and irreversible impacts for people, species and ecosystems. Continued high emissions would lead to mostly negative impacts for biodiversity, ecosystem services and economic development and amplify risks for livelihoods and for food and human security.

Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems, including their ability to adapt. Rising rates and magnitudes of warming and other changes in the climate system, accompanied by ocean acidification, increase the risk of severe, pervasive, and in some cases, irreversible detrimental impacts. Future climate change will amplify existing climate-related risks and create new risks. *{WGII SPM B, Figure SPM.1}*

Key risks are potentially severe impacts relevant to understanding dangerous anthropogenic interference with the climate system. Risks are considered key due to high hazard or high vulnerability of societies and systems exposed, or both. Their identification is based on large magnitude or high probability of impacts; irreversibility or timing of impacts; persistent vulnerability or exposure; or limited potential to reduce risks. Some risks are particularly relevant for individual regions (Figure 2.4), while others are global (Table 2.3). For risk assessment it is important to evaluate the widest possible range of impacts, including low-probability outcomes with large consequences. Risk levels often increase with temperature (Box 2.4) and are sometimes more directly linked to other dimensions of climate change, such as the rate of warming, as well as the magnitudes and rates of ocean acidification and sea level rise (Figure 2.5). *{WGII SPM A-3, SPM B-1}*

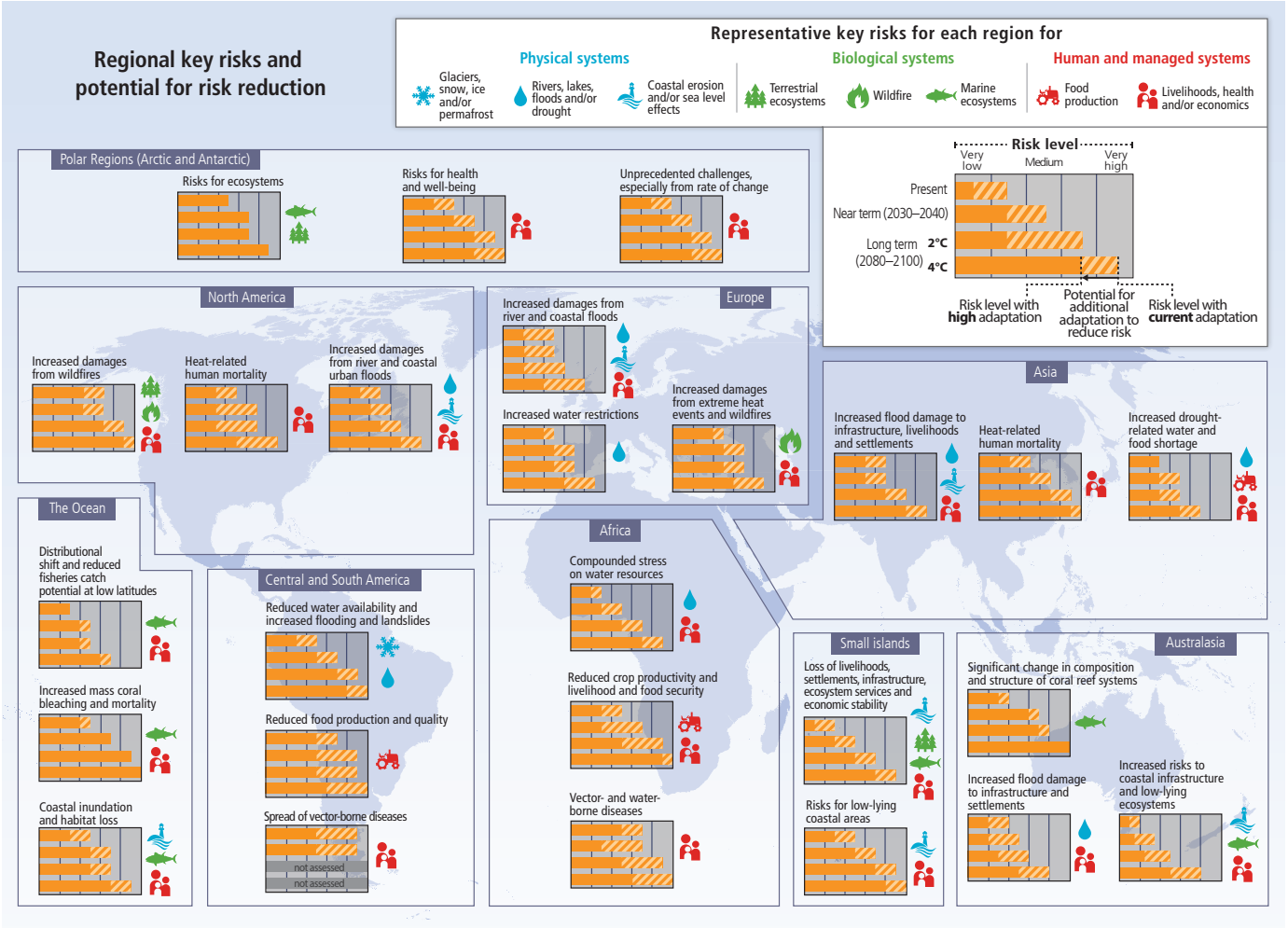


Figure 2.4 | Representative key risks for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation. Identification of key risks was based on expert judgment using the following specific criteria: large magnitude, high probability or irreversibility of impacts; timing of impacts; persistent vulnerability or exposure contributing to risks; or limited potential to reduce risks through adaptation or mitigation. Risk levels are assessed as very low, low, medium, high or very high for three timeframes: the present, near term (here, for 2030–2040) and long term (here, for 2080–2100). In the near term, projected levels of global mean temperature increase do not diverge substantially across different emission scenarios. For the long term, risk levels are presented for two possible futures (2°C and 4°C global mean temperature increase above pre-industrial levels). For each time frame, risk levels are indicated for a continuation of current adaptation and assuming high levels of current or future adaptation. Risk levels are not necessarily comparable, especially across regions. *{WGII SPM Assessment Box SPM.2 Table 1}*

Key risks that span sectors and regions include the following (*high confidence*) *{WGII SPM B-1}*:

1. Risk of severe ill-health and disrupted livelihoods resulting from storm surges, sea level rise and coastal flooding; inland flooding in some urban regions; and periods of extreme heat.

2. Systemic risks due to extreme weather events leading to breakdown of infrastructure networks and critical services.

3. Risk of food and water insecurity and loss of rural livelihoods and income, particularly for poorer populations.

4. Risk of loss of ecosystems, biodiversity and ecosystem goods, functions and services.

The overall risks of future climate change impacts can be reduced by limiting the rate and magnitude of climate change, including ocean acidification. Some risks are considerable even at 1°C global mean temperature increase above pre-industrial levels. Many global risks are high to very high for global temperature increases of 4°C or more (see Box 2.4). These risks include severe and widespread impacts on unique and threatened systems, the extinction of many species, large risks to food security and compromised normal human activities, including growing food or working outdoors in some areas for parts of the year, due to the combination of high temperature and humidity (*high confidence*). The precise levels of climate change sufficient to trigger abrupt and irreversible change remain uncertain, but the risk associated with crossing such thresholds in the earth system or in interlinked human and natural systems increases with rising temperature (*medium confidence*). *{WGII SPM B-1}*

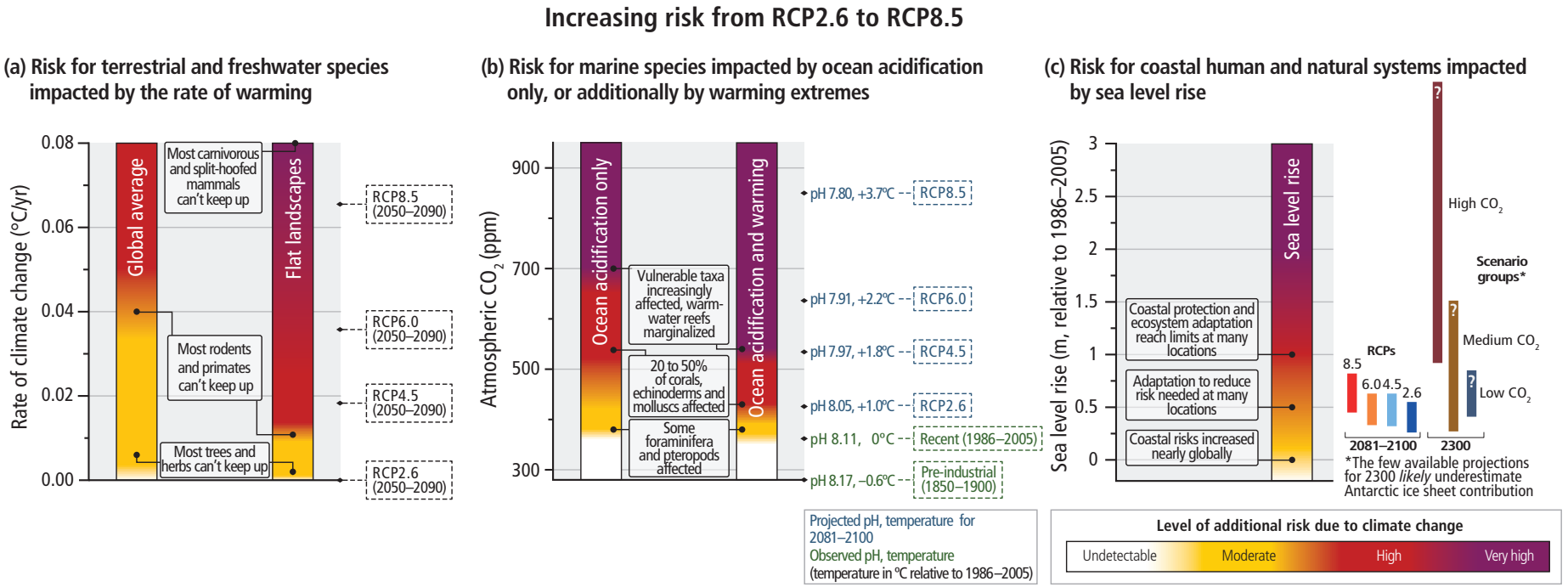


Figure 2.5 | The risks of: **(a)** disruption of the community composition of terrestrial and freshwater ecosystems due to the rate of warming; **(b)** marine organisms impacted by ocean acidification (OA) or warming extremes combined with OA; and **(c)** coastal human and natural systems impacted by sea level rise. The risk level criteria are consistent with those used in Box 2.4 and their calibration is illustrated by the annotations to each panel. **(a)** At high rates of warming, major groups of terrestrial and freshwater species are unable to move fast enough to stay within the spatially shifting climate envelopes to which they are adapted. The median observed or modelled speeds at which species populations move (km/decade) are compared against the speed at which climate envelopes move across the landscape, given the projected climate change rates for each Representative Concentration Pathway (RCP) over the 2050–2090 period. The results are presented for the average of all landscapes, globally, as well as for flat landscapes, where the climate envelope moves especially fast. **(b)** Sensitivity to ocean acidification is high in marine organisms building a calcium carbonate shell. The risks from OA increase with warming because OA lowers the tolerated levels of heat exposure, as seen in corals and crustaceans. **(c)** The height of a 50-year flood event has already increased in many coastal locations. A 10- to more than 100-fold increase in the frequency of floods in many places would result from a 0.5 m rise in sea level in the absence of adaptation. Local adaptation capacity (and, in particular, protection) reaches its limits for ecosystems and human systems in many places under a 1 m sea level rise. (2.2.4, Table 2.1, Figure 2.8) *{WGI 3.7.5, 3.8, 6.4.4, Figure 13.25, WGII Figure SPM.5, Figure 4-5, Figure 6-10, Box CC-OA, 4.4.2.5, 5.2, 5.3–5.5, 5.4.4, 5.5.6, 6.3}*

Adaptation can substantially reduce the risks of climate change impacts, but greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*). The potential for adaptation, as well as constraints and limits to adaptation, varies among sectors, regions, communities and ecosystems. The scope for adaptation changes over time and is closely linked to socio-economic development pathways and circumstances. See Figure 2.4 and Table 2.3, along with Topics 3 and 4. *{WGII SPM B, SPM C, TS B, TS C}*

2.3.1 Ecosystems and their services in the oceans, along coasts, on land and in freshwater

Risks of harmful impacts on ecosystems and human systems increase with the rates and magnitudes of warming, ocean acidification, sea level rise and other dimensions of climate change (*high confidence*). Future risk is indicated to be high by the observation that natural global climate change at rates lower than current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years on land and in the oceans (*high confidence*). Many plant and animal species will be unable to adapt locally or move fast enough during the 21st century to track suitable climates under mid- and high range rates of climate change (RCP4.5, RCP6.0 and RCP8.5) (*medium confidence*) (Figure 2.5a). Coral reefs and polar ecosystems are highly vulnerable. *{WGII SPM A-1, SPM B-2, 4.3–4, 5.4, 6.1, 6.3, 6.5, 25.6, 26.4, 29.4, Box CC-CR, Box CC-MB, Box CC-RF}*

A large fraction of terrestrial, freshwater and marine species faces increased extinction risk due to climate change during and beyond the 21st century, especially as climate change interacts with other stressors (*high confidence*). Extinction risk is increased relative to pre-industrial and present periods, under all RCP scenarios, as a result of both the magnitude and rate of climate change (*high confidence*). Extinctions will be driven by several climate-associated drivers (warming, sea-ice loss, variations in precipitation, reduced river flows, ocean acidification and lowered ocean oxygen levels) and the interactions among these drivers and their interaction with simultaneous habitat modification, over-exploitation of stocks, pollution, eutrophication and invasive species (*high confidence*). *{WGII SPM B-2, 4.3–4.4, 6.1, 6.3, 6.5, 25.6, 26.4, Box CC-RF, Box CC-MB}*

Global marine species redistribution and marine biodiversity reduction in sensitive regions, under climate change, will challenge the sustained provision of fisheries productivity and other ecosystem services, especially at low latitudes (*high confidence*). By the mid-21st century, under 2°C global warming relative to pre-industrial temperatures, shifts in the geographical range of marine species will cause species richness and fisheries catch potential to increase, on average, at mid and high latitudes (*high confidence*) and to decrease at tropical latitudes and in semi-enclosed seas (Figure 2.6a) (*medium confidence*). The progressive expansion of Oxygen Minimum Zones and anoxic 'dead zones' in the oceans will further constrain fish habitats (*medium confidence*). Open-ocean net primary production is projected to redistribute and to decrease globally, by 2100, under all RCP scenarios (*medium confidence*). Climate change adds to the threats of over-fishing and other non-climatic stressors (*high confidence*). *{WGII SPM B-2, 6.3–6.5, 7.4, 25.6, 28.3, 29.3, 30.6–30.7, Box CC-MB, Box CC-PP}*

Marine ecosystems, especially coral reefs and polar ecosystems, are at risk from ocean acidification (*medium* to *high confidence*). Ocean acidification has impacts on the physiology, behaviour and population dynamics of organisms. The impacts on individual species and the number of species affected in species groups increase from RCP4.5 to RCP8.5. Highly calcified molluscs, echinoderms and reef-building corals are more sensitive than crustaceans (*high confidence*) and fishes (*low confidence*) (Figure 2.6b). Ocean acidification acts together with other global changes (e.g., warming, progressively lower oxygen levels) and with local changes (e.g., pollution, eutrophication) (*high confidence*), leading to interactive, complex and amplified impacts for species and ecosystems (Figure 2.5b). *{WGII SPM B-2, Figure SPM.6B, 5.4, 6.3.2, 6.3.5, 22.3, 25.6, 28.3, 30.5, Figure 6-10, Box CC-CR, Box CC-OA, Box TS.7}*

Carbon stored in the terrestrial biosphere is susceptible to loss to the atmosphere as a result of climate change, deforestation and ecosystem degradation (*high confidence*). The aspects of climate change with direct effects on stored terrestrial carbon include high temperatures, drought and windstorms; indirect effects include increased risk of fires, pest and disease outbreaks. Increased tree mortality and associated forest dieback is projected to occur in many regions over the 21st century (*medium confidence*), posing risks for carbon storage, biodiversity, wood production, water quality, amenity and economic activity. There is a high risk of substantial carbon and methane emissions as a result of permafrost thawing. *{WGII SPM, 4.2–4.3, Figure 4-8, Box 4-2, Box 4-3, Box 4-4}*

Coastal systems and low-lying areas will increasingly experience submergence, flooding and erosion throughout the 21st century and beyond, due to sea level rise (*very high confidence*). The population and assets projected to be exposed to coastal risks as well as human pressures on coastal ecosystems will increase significantly in the coming decades due to population growth, economic development and urbanization (*high confidence*). Climatic and non-climatic drivers affecting coral reefs will erode habitats, increase coastline exposure to waves and storms and degrade environmental features important to fisheries and tourism (*high confidence*). Some low-lying developing countries and small island states are expected to face very high impacts that could have associated damage and adaptation costs of several percentage points of gross domestic product (GDP) (Figure 2.5c). *{WGII 5.3–5.5, 22.3, 24.4, 25.6, 26.3, 26.8, 29.4, Table 26-1, Box 25-1, Box CC-CR}*

2.3.2 Water, food and urban systems, human health, security and livelihoods

The fractions of the global population that will experience water scarcity and be affected by major river floods are projected to increase with the level of warming in the 21st century (*robust evidence, high agreement*). *{WGII 3.4–3.5, 26.3, 29.4, Table 3-2, Box 25-8}*

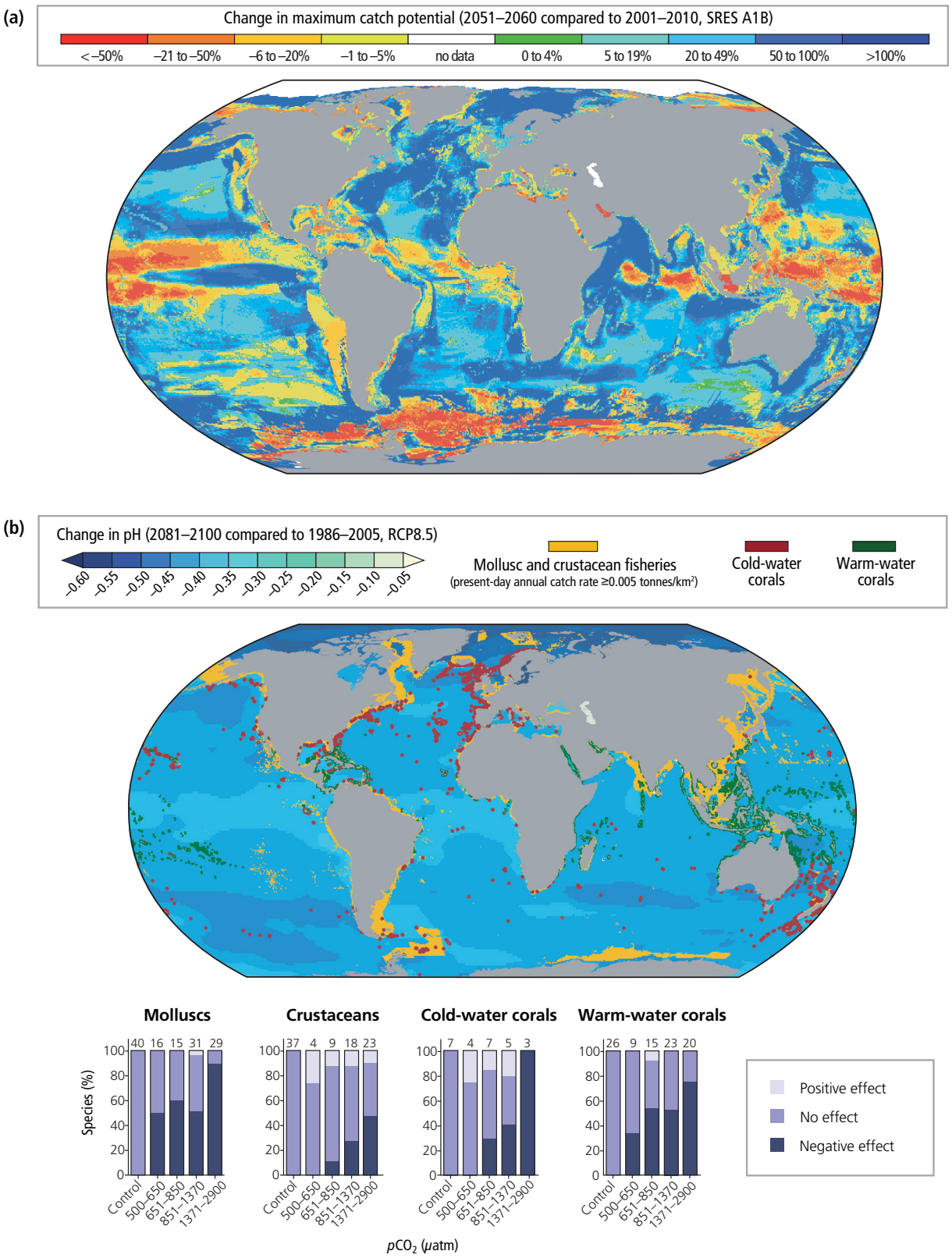


Figure 2.6 | Climate change risks for fisheries. **(a)** Projected global redistribution of maximum catch potential of ~1000 species of exploited fishes and invertebrates, comparing the 10-year averages over 2001–2010 and 2051–2060, using ocean conditions based on a single climate model under a moderate to high warming scenario (2°C warming relative to pre-industrial temperatures), without analysis of potential impacts of overfishing or ocean acidification. **(b)** Marine mollusc and crustacean fisheries (present-day estimated annual catch rates ≥0.005 tonnes/km²) and known locations of cold- and warm-water corals, depicted on a global map showing the projected distribution of surface ocean acidification by 2100 under RCP8.5. The bottom panel compares the percentage of species sensitive to ocean acidification for corals, molluscs and crustaceans, vulnerable animal phyla with socio-economic relevance (e.g., for coastal protection and fisheries). The number of species analysed across studies is given on top of the bars for each category of elevated CO_2. For 2100, RCP scenarios falling within each pCO_2 category are as follows: RCP4.5 for 500 to 650 µatm, RCP6.0 for 651 to 850 µatm and RCP8.5 for 851 to 1370 µatm. By 2150, RCP8.5 falls within the 1371 to 2900 µatm category. The control category corresponds to 380 µatm (The unit µatm is approximately equivalent to ppm in the atmosphere). *{WGI Figure SPM.8, Box SPM.1, WGII SPM B-2, Figure SPM.6, 6.1, 6.3, 30.5, Figure 6-10 , Figure 6-14}*

Climate change over the 21st century is projected to reduce renewable surface water and groundwater resources in most dry subtropical regions (*robust evidence*, *high agreement*), intensifying competition for water among sectors (*limited evidence*, *medium agreement*). In presently dry regions, the frequency of droughts will *likely* increase by the end of the 21st century under RCP8.5 (*medium confidence*). In contrast, water resources are projected to increase at high latitudes (*robust evidence, high agreement*). The interaction of increased temperature; increased sediment, nutrient and pollutant loadings from heavy rainfall; increased concentrations of pollutants during droughts; and disruption of treatment facilities during floods will reduce raw water quality and pose risks to drinking water quality (*medium evidence, high agreement*). *{WGI 12.4, WGII 3.2, 3.4–3.6, 22.3, 23.9, 25.5, 26.3, Table 3-2, Table 23-3, Box 25-2, Box CC-RF, Box CC-WE}*

All aspects of food security are potentially affected by climate change, including food production, access, use and price stability (*high confidence*). For wheat, rice and maize in tropical and temperate regions, climate change without adaptation is projected to negatively impact production at local temperature increases of 2°C or more above late 20th century levels, although individual locations may benefit (*medium confidence*). Projected impacts vary across crops and regions and adaptation scenarios, with about 10% of projections for the 2030–2049 period showing yield gains of more than 10%, and about 10% of projections showing yield losses of more than 25%, compared with the late 20th century. Global temperature increases of ~4°C or more above late 20th century levels, combined with increasing food demand, would pose large risks to food security, both globally and regionally (*high confidence*) (Figure 2.4, 2.7). The relationship between global and regional warming is explained in 2.2.1. *{WGII 6.3–6.5, 7.4–7.5, 9.3, 22.3, 24.4, 25.7, 26.5, Table 7-2, Table 7-3, Figure 7-1, Figure 7-4, Figure 7-5, Figure 7-6, Figure 7-7, Figure 7-8, Box 7-1}*

Until mid-century, projected climate change will impact human health mainly by exacerbating health problems that already exist (*very high confidence*). Throughout the 21st century, climate change is expected to lead to increases in ill-health in many regions and especially in developing countries with low income, as compared to a baseline without climate change (*high confidence*). Health impacts include greater likelihood of injury and death due to more intense heat waves and fires, increased risks from foodborne and waterborne diseases and loss of work capacity and reduced labour productivity in vulnerable populations (*high confidence*). Risks of undernutrition in poor regions will increase (*high confidence*). Risks from vector-borne diseases are projected to generally increase with warming, due to the extension of the infection area and season, despite reductions in some areas that become too hot for disease vectors (*medium confidence*). Globally, the magnitude and severity of negative impacts will increasingly outweigh positive impacts (*high confidence*). By 2100 for RCP8.5, the combination of high temperature and humidity in some areas for parts of the year is expected to compromise common human activities, including growing food and working outdoors (*high confidence*). *{WGII SPM B-2, 8.2, 11.3–11.8, 19.3, 22.3, 25.8, 26.6, Figure 25-5, Box CC-HS}*

In urban areas, climate change is projected to increase risks for people, assets, economies and ecosystems, including risks from heat stress, storms and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea level rise and storm surges (*very high confidence*). These risks will be amplified for those lacking essential infrastructure and services or living in exposed areas. *{WGII 3.5, 8.2–8.4, 22.3, 24.4–24.5, 26.8, Table 8-2, Box 25-9, Box CC-HS}*

Rural areas are expected to experience major impacts on water availability and supply, food security, infrastructure and agricultural incomes, including shifts in the production areas of food and non-food crops around the world (*high confidence*). These impacts will disproportionately affect the welfare of the poor in rural areas, such as female-headed households and those with limited access to land, modern agricultural inputs, infrastructure and education. *{WGII 5.4, 9.3, 25.9, 26.8, 28.2, 28.4, Box 25-5}*

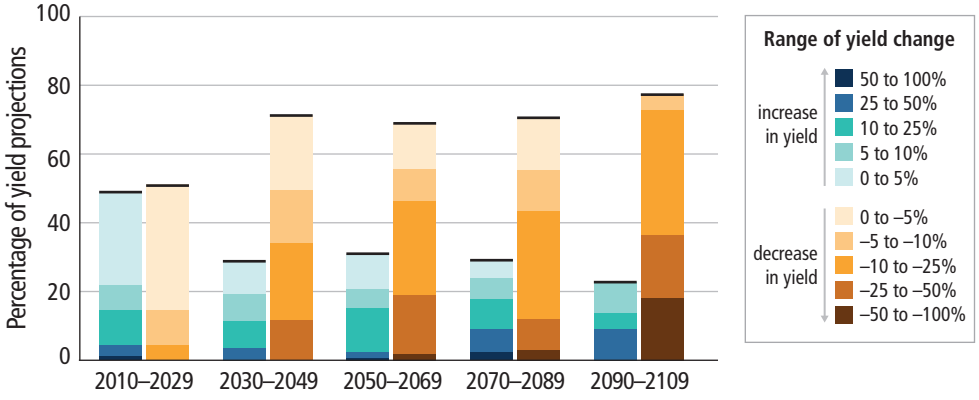
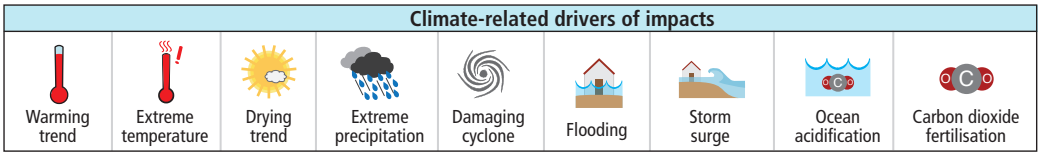
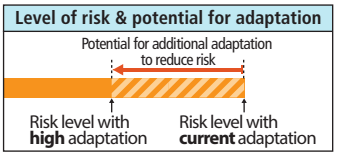


Figure 2.7 | Summary of projected changes in crop yields (mostly wheat, maize, rice and soy) due to climate change over the 21st century. The figure combines 1090 data points from crop model projections, covering different emission scenarios, tropical and temperate regions and adaptation and no-adaptation cases. The projections are sorted into the 20-year periods (horizontal axis) during which their midpoint occurs. Changes in crop yields are relative to late 20th century levels and data for each time period sum to 100%. Relatively few studies have considered impacts on cropping systems for scenarios where global mean temperatures increase by 4°C or more. *{WGII Figure SPM.7}*

Table 2.3 | Examples of global key risks for different sectors, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation. Each key risk is assessed as very low, low, medium, high or very high. Risk levels are presented for three time frames: present, near term (here, for 2030–2040) and long term (here, for 2080–2100). In the near term, projected levels of global mean temperature increase do not diverge substantially across different emission scenarios. For the long term, risk levels are presented for two possible futures (2°C and 4°C global mean temperature increase above pre-industrial levels). For each time frame, risk levels are indicated for a continuation of current adaptation and assuming high levels of current or future adaptation. Risk levels are not necessarily comparable, especially across regions. Relevant climate variables are indicated by icons. *{WGII Table TS.4}*

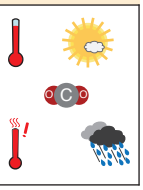
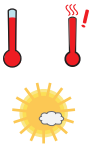




Global Risks

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Reduction in terrestrial carbon sink: Carbon stored in terrestrial ecosystems is vulnerable to loss back into the atmosphere, resulting from increased fire frequency due to climate change and the sensitivity of ecosystem respiration to rising temperatures (*medium confidence*) *{WGII 4.2, 4.3}*	• Adaptation options include managing land use (including deforestation), fire and other disturbances, and non-climatic stressors.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Boreal tipping point: Arctic ecosystems are vulnerable to abrupt change related to the thawing of permafrost, spread of shrubs in tundra and increase in pests and fires in boreal forests (*medium confidence*) *{WGII 4.3, Box 4-4}*	• There are few adaptation options in the Arctic.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Amazon tipping point: Moist Amazon forests could change abruptly to less-carbon-dense, drought- and fire-adapted ecosystems (*low confidence*) *{WGII 4.3, Box 4-3}*	• Policy and market measures can reduce deforestation and fire.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Increased risk of species extinction: A large fraction of the species assessed is vulnerable to extinction due to climate change, often in interaction with other threats. Species with an intrinsically low dispersal rate, especially when occupying flat landscapes where the projected climate velocity is high, and species in isolated habitats such as mountaintops, islands or small protected areas are especially at risk. Cascading effects through organism interactions, especially those vulnerable to phenological changes, amplify risk (*high confidence*) *{WGII 4.3, 4.4}*	• Adaptation options include reduction of habitat modification and fragmentation, pollution, over-exploitation and invasive species; protected area expansion; assisted dispersal; and *ex situ* conservation.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Global redistribution and decrease of low-latitude fisheries yields, paralleled by a global trend to catches having smaller fishes (*medium confidence*) *{WGII 6.3 to 6.5, 30.5, 30.6}*	• Increasing coastal poverty at low latitudes as fisheries become smaller – partially compensated by the growth of aquaculture and marine spatial planning, as well as enhanced industrialized fishing efforts		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Reduced growth and survival of commercially valuable shellfish and other calcifiers (e.g., reef building corals, calcareous red algae) due to ocean acidification (*high confidence*) *{WGII 5.3, 6.1, 6.3, 6.4, 30.3, Box CC-OA}*	• Evidence for differential resistance and evolutionary adaptation of some species exists, but they are *likely* to be limited at higher CO_2 concentrations and temperatures. • Adaptation options include exploiting more resilient species or protecting habitats with low natural CO_2 levels, as well as reducing other stresses, mainly pollution, and limiting pressures from tourism and fishing.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Marine biodiversity loss with high rate of climate change (*medium confidence*) *{WGII 6.3, 6.4, Table 30-4, Box CC-MB}*	• Adaptation options are limited to reducing other stresses, mainly pollution, and limiting pressures from coastal human activities such as tourism and fishing.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high

Table 2.3 *(continued)*

Global Risks				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
Negative impacts on average crop yields and increases in yield variability due to climate change (*high confidence*) *{WGII 7.2 to 7.5, Figure 7-5, Box 7-1}*	• Projected impacts vary across crops and regions and adaptation scenarios, with about 10% of projections for the period 2030–2049 showing yield gains of more than 10%, and about 10% of projections showing yield losses of more than 25%, compared to the late 20th century. After 2050 the risk of more severe yield impacts increases and depends on the level of warming.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Urban risks associated with water supply systems (*high confidence*) *{WGII 8.2, 8.3}*	• Adaptation options include changes to network infrastructure as well as demand-side management to ensure sufficient water supplies and quality, increased capacities to manage reduced freshwater availability, and flood risk reduction.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Urban risks associated with energy systems (*high confidence*) *{WGII 8.2, 8.4}*	• Most urban centers are energy intensive, with energy-related climate policies focused only on mitigation measures. A few cities have adaptation initiatives underway for critical energy systems. There is potential for non-adapted, centralised energy systems to magnify impacts, leading to national and transboundary consequences from localised extreme events.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Urban risks associated with housing (*high confidence*) *{WGII 8.3}*	• Poor quality, inappropriately located housing is often most vulnerable to extreme events. Adaptation options include enforcement of building regulations and upgrading. Some city studies show the potential to adapt housing and promote mitigation, adaptation and development goals simultaneously. Rapidly growing cities, or those rebuilding after a disaster, especially have opportunities to increase resilience, but this is rarely realised. Without adaptation, risks of economic losses from extreme events are substantial in cities with high-value infrastructure and housing assets, with broader economic effects possible.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Displacement associated with extreme events (*high confidence*) *{WGII 12.4}*	• Adaptation to extreme events is well understood, but poorly implemented even under present climate conditions. Displacement and involuntary migration are often temporary. With increasing climate risks, displacement is more likely to involve permanent migration.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Violent conflict arising from deterioration in resource-dependent livelihoods such as agriculture and pastoralism (*high confidence*) *{WGII 12.5}*	Adaptation options: • Buffering rural incomes against climate shocks, for example through livelihood diversification, income transfers and social safety net provision • Early warning mechanisms to promote effective risk reduction • Well-established strategies for managing violent conflict that are effective but require significant resources, investment and political will		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Declining work productivity, increasing morbidity (e.g., dehydration, heat stroke and heat exhaustion), and mortality from exposure to heat waves. Particularly at risk are agricultural and construction workers as well as children, homeless people, the elderly, and women who have to walk long hours to collect water (*high confidence*) *{WGII 13.2, Box 13-1}*	• Adaptation options are limited for people who are dependent on agriculture and cannot afford agricultural machinery. • Adaptation options are limited in the construction sector where many poor people work under insecure arrangements. • Adaptation limits may be exceeded in certain areas in a +4°C world.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Reduced access to water for rural and urban poor people due to water scarcity and increasing competition for water (*high confidence*) *{WGII 13.2, Box 13-1}*	• Adaptation through reducing water use is not an option for the many people already lacking adequate access to safe water. Access to water is subject to various forms of discrimination, for instance due to gender and location. Poor and marginalised water users are unable to compete with water extraction by industries, large-scale agriculture and other powerful users.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high

Box 2.4 | Reasons For Concern Regarding Climate Change

Five Reasons For Concern (RFCs) have provided a framework for summarizing key risks since the IPCC Third Assessment Report. They illustrate the implications of warming and of adaptation limits for people, economies and ecosystems across sectors and regions. They provide one starting point for evaluating dangerous anthropogenic interference with the climate system. All warming levels in the text of Box 2.4 are relative to the 1986–2005 period. Adding ~0.6°C to these warming levels roughly gives warming relative to the 1850–1900 period, used here as a proxy for pre-industrial times (right-hand scale in Box 2.4, Figure 1). *{WGII Assessment Box SPM.1}*

The five RFCs are associated with:

1. **Unique and threatened systems:** Some ecosystems and cultures are already at risk from climate change (*high confidence*). With additional warming of around 1°C, the number of unique and threatened systems at risk of severe consequences increases. Many systems with limited adaptive capacity, particularly those associated with Arctic sea ice and coral reefs, are subject to very high risks with additional warming of 2°C. In addition to risks resulting from the *magnitude* of warming, terrestrial species are also sensitive to the *rate* of warming, marine species to the rate and degree of ocean acidification and coastal systems to sea level rise (Figure 2.5).

2. **Extreme weather events:** Climate change related risks from extreme events, such as heat waves, heavy precipitation and coastal flooding, are already moderate (*high confidence*). With 1°C additional warming, risks are high (*medium confidence*). Risks associated with some types of extreme events (e.g., extreme heat) increase progressively with further warming (*high confidence*).

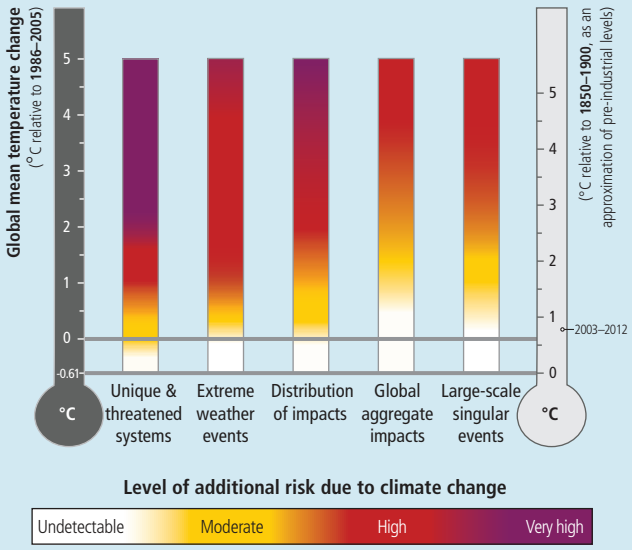
3. **Distribution of impacts:** Risks are unevenly distributed between groups of people and between regions; risks are generally greater for disadvantaged people and communities everywhere. Risks are already moderate because of regional differences in observed climate change impacts, particularly for crop production (*medium* to *high confidence*). Based on projected decreases in regional crop yields and water availability, risks of unevenly distributed impacts are high under additional warming of above 2°C (*medium confidence*).

4. **Global aggregate impacts:** Risks of global aggregate impacts are moderate under additional warming of between 1°C and 2°C, reflecting impacts on both the Earth's biodiversity and the overall global economy (*medium confidence*). Extensive biodiversity loss, with associated loss of ecosystem goods and services, leads to high risks at around 3°C additional warming (*high confidence*). Aggregate economic damages accelerate with increasing temperature (*limited evidence*, *high agreement*), but few quantitative estimates are available for additional warming of above 3°C.

5. **Large-scale singular events:** With increasing warming, some physical and ecological systems are at risk of abrupt and/or irreversible changes (see Section 2.4). Risks associated with such tipping points are moderate between 0 and 1°C additional warming, since there are signs that both warm-water coral reefs and Arctic ecosystems are already experiencing irreversible regime shifts (*medium confidence*). Risks increase at a steepening rate under an additional warming of 1 to 2°C and become high above 3°C, due to the potential for large and irreversible sea level rise from ice sheet loss. For sustained warming above some threshold greater than ~0.5°C additional warming (*low confidence*) but less than ~3.5°C (*medium confidence*), near-complete loss of the Greenland ice sheet would occur over a millennium or more, eventually contributing up to 7 m to global mean sea level rise.

(continued on next page)

Box 2.4 *(continued)*



Box 2.4, Figure 1 | Risks associated with Reasons For Concern at a global scale are shown for increasing levels of climate change. The colour shading indicates the additional risk due to climate change when a temperature level is reached and then sustained or exceeded. White indicates no associated impacts are detectable and attributable to climate change. Yellow indicates that associated impacts are both detectable and attributable to climate change with at least *medium confidence*. Red indicates severe and widespread impacts. Purple, introduced in this assessment, shows that very high risk is indicated by all key risk criteria. *{WGII Assessment Box SPM.1, Figure 19-4}*

Aggregate economic losses accelerate with increasing temperature (*limited evidence, high agreement*), but global economic impacts from climate change are currently difficult to estimate. With recognized limitations, the existing incomplete estimates of global annual economic losses for warming of ~2.5°C above pre-industrial levels are 0.2 to 2.0% of income (*medium evidence, medium agreement*). Changes in population, age structure, income, technology, relative prices, lifestyle, regulation and governance are projected to have relatively larger impacts than climate change, for most economic sectors (*medium evidence, high agreement*). More severe and/or frequent weather hazards are projected to increase disaster-related losses and loss variability, posing challenges for affordable insurance, particularly in developing countries. International dimensions such as trade and relations among states are also important for understanding the risks of climate change at regional scales. (Box 3.1) *{WGII 3.5, 10.2, 10.7, 10.9–10.10, 17.4–17.5, 25.7, 26.7–26.9, Box 25-7}*

From a poverty perspective, climate change impacts are projected to slow down economic growth, make poverty reduction more difficult, further erode food security and prolong existing poverty traps and create new ones, the latter particularly in urban areas and emerging hotspots of hunger (*medium confidence*). Climate change impacts are expected to exacerbate poverty in most developing countries and create new poverty pockets in countries with increasing inequality, in both developed and developing countries (Figure 2.4). *{WGII 8.1, 8.3–8.4, 9.3, 10.9, 13.2–13.4, 22.3, 26.8}*

Climate change is projected to increase displacement of people (*medium evidence, high agreement*). Displacement risk increases when populations that lack the resources for planned migration experience higher exposure to extreme weather events, such as floods and droughts. Expanding opportunities for mobility can reduce vulnerability for such populations. Changes in migration patterns can be responses to both extreme weather events and longer term climate variability and change, and migration can also be an effective adaptation strategy. *{WGII 9.3, 12.4, 19.4, 22.3, 25.9}*

Climate change can indirectly increase risks of violent conflict by amplifying well-documented drivers of these conflicts, such as poverty and economic shocks (*medium confidence*). Multiple lines of evidence relate climate variability to some forms of conflict. *{WGII SPM, 12.5, 13.2, 19.4}*

2.4 Climate change beyond 2100, irreversibility and abrupt changes

Many aspects of climate change and its associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. The risks of abrupt or irreversible changes increase as the magnitude of the warming increases.

Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions (see Section 2.2.5 for the relationship between CO_2 emissions and global temperature change.). A large fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial timescale, except in the

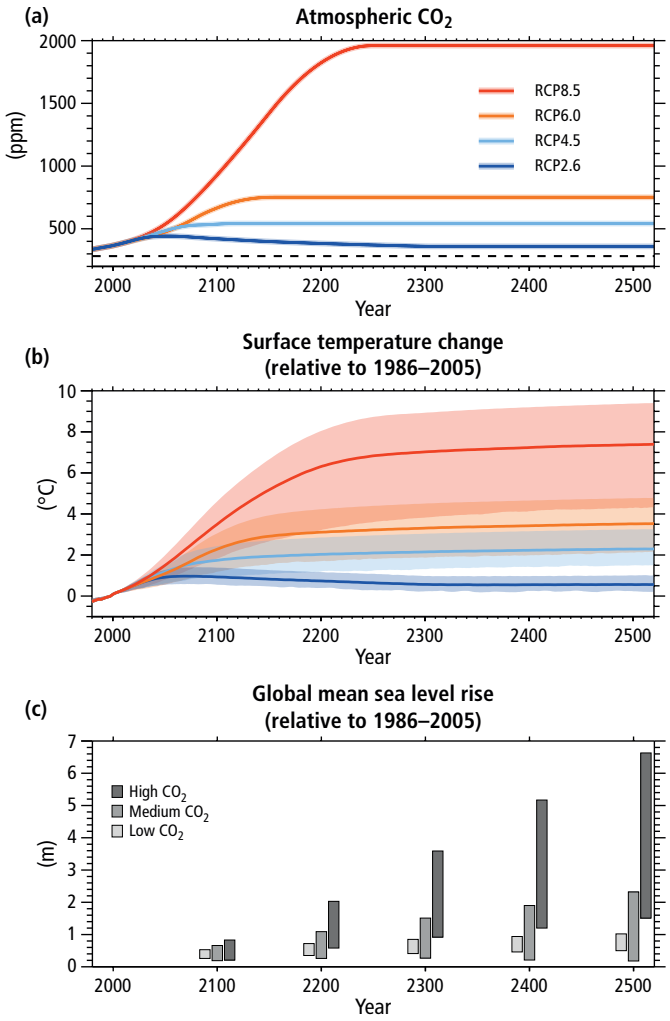


Figure 2.8 | **(a)** Atmospheric carbon dioxide (CO_2) and **(b)** projected global mean surface temperature change as simulated by Earth System Models of Intermediate Complexity (EMICs) for the four Representative Concentration Pathways (RCPs) up to 2300 (relative to 1986–2005) followed by a constant (year 2300 level) radiative forcing. A 10-year smoothing was applied. The dashed line on (a) indicates the pre-industrial CO_2 concentration. **(c)** Sea level change projections grouped into three categories according to the concentration of greenhouse gas (in CO_2-eq) in 2100 (low: concentrations that peak and decline and remain below 500 ppm, as in scenario RCP2.6; medium: 500 to 700 ppm, including RCP4.5; high: concentrations that are above 700 ppm but below 1500 ppm, as in scenario RCP6.0 and RCP8.5). The bars in (c) show the maximum possible spread that can be obtained with the few available model results (and should not be interpreted as uncertainty ranges). These models *likely* underestimate the Antarctica ice sheet contribution, resulting in an underestimation of projected sea level rise beyond 2100. *{WGI Figure 12.43, Figure 13.13, Table 13.8, WGII SPM B-2}*

case of a large net removal of CO_2 from the atmosphere over a sustained period (Figure 2.8a, b). *{WGI SPM E.1, SPM E.8, 12.5.2}*

Stabilization of global average surface temperature does not imply stabilization for all aspects of the climate system. Shifting biomes, re-equilibrating soil carbon, ice sheets, ocean temperatures and associated sea level rise all have their own intrinsic long timescales that will result in ongoing changes for hundreds to thousands of years after global surface temperature has been stabilized. *{WGI SPM E.8, 12.5.2–12.5.4, WGII 4.2}*

Ocean acidification will continue for centuries if CO_2 emissions continue, it will strongly affect marine ecosystems (*high confidence*), and the impact will be exacerbated by rising temperature extremes (Figure 2.5b). ***{WGI 3.8.2, 6.4.4, WGII SPM B-2, 6.3.2, 6.3.5, 30.5, Box CC-OA}***

Global mean sea level rise will continue for many centuries beyond 2100 (*virtually certain*). The few available analyses that go beyond 2100 indicate sea level rise to be less than 1 m above the pre-industrial level by 2300 for GHG concentrations that peak and decline and remain below 500 ppm CO_2-eq, as in scenario RCP2.6. For a radiative forcing that corresponds to a CO_2-eq concentration in 2100 that is above 700 ppm but below 1500 ppm, as in scenario RCP8.5, the projected rise is 1 m to more than 3 m by 2300 (*medium confidence*) (Figure 2.8c). There is *low confidence* in the available models' ability to project solid ice discharge from the Antarctic ice sheet. Hence, these models *likely* underestimate the Antarctica ice sheet contribution, resulting in an underestimation of projected sea level rise beyond 2100. *{WGI SPM E.8, 13.4.4, 13.5.4}*

There is little evidence in global climate models of a tipping point or critical threshold in the transition from a perennially ice-covered to a seasonally ice-free Arctic Ocean, beyond which further sea-ice loss is unstoppable and irreversible. *{WGI 12.5.5}*

There is *low confidence* in assessing the evolution of the Atlantic Meridional Overturning Circulation beyond the 21st century because of the limited number of analyses and equivocal results. However, a collapse beyond the 21st century for large sustained warming cannot be excluded. *{WGI SPM E.4, 12.4.7, 12.5.5}*

Sustained mass loss by ice sheets would cause larger sea level rise, and part of the mass loss might be irreversible. There is *high confidence* that sustained global mean warming greater than a threshold would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a sea level rise of up to 7 m. Current estimates indicate that the threshold is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) of global warming with respect to pre-industrial temperatures. Abrupt and irreversible ice loss from a potential instability of marine-based sectors of the Antarctic ice sheet in response to climate forcing is possible, but current evidence and understanding is insufficient to make a quantitative assessment. *{WGI SPM E.8, 5.6.2, 5.8.1, 13.4.3, 13.5.4}*

Within the 21st century, magnitudes and rates of climate change associated with medium to high emission scenarios (RCP4.5, RCP6.0 and RCP8.5) pose a high risk of abrupt and irreversible regional-scale change in the composition, structure and function of marine, terrestrial and freshwater ecosystems, including wetlands (*medium confidence*), as well as warm water coral reefs (*high confidence*). Examples that could substantially amplify climate change are the boreal-tundra Arctic system (*medium confidence*) and the Amazon forest (*low confidence*). *{WGII 4.3.3.1, Box 4.3, Box 4.4, 5.4.2.4, 6.3.1–6.3.4, 6.4.2, 30.5.3–30.5.6, Box CC-CR, Box CC-MB}*

A reduction in permafrost extent is *virtually certain* with continued rise in global temperatures. Current permafrost areas are projected to become a net emitter of carbon (CO_2 and CH_4) with a loss of 180 to 920 $GtCO_2$ (50 to 250 GtC) under RCP8.5 over the 21st century (*low confidence*). *{WGI TFE.5, 6.4.3.4, 12.5.5, WGII 4.3.3.4}*

3 Future Pathways for Adaptation, Mitigation and Sustainable Development

Topic 3: Future Pathways for Adaption, Mitigation and Sustainable Development

Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to climate-resilient pathways for sustainable development.

Adaptation and mitigation are two complementary strategies for responding to climate change. Adaptation is the process of adjustment to actual or expected climate and its effects in order to either lessen or avoid harm or exploit beneficial opportunities. Mitigation is the process of reducing emissions or enhancing sinks of greenhouse gases (GHGs), so as to limit future climate change. Both adaptation and mitigation can reduce and manage the risks of climate change impacts. Yet adaptation and mitigation can also create other risks, as well as benefits. Strategic responses to climate change involve consideration of climate-related risks along with the risks and co-benefits of adaptation and mitigation actions. *{WGII SPM A-3, SPM C, Glossary, WGIII SPM.2, 4.1, 5.1, Glossary}*

Mitigation, adaptation and climate impacts can all result in transformations to and changes in systems. Depending on the rate and magnitude of change and the vulnerability and exposure of human and natural systems, climate change will alter ecosystems, food systems, infrastructure, coastal, urban and rural areas, human health and livelihoods. Adaptive responses to a changing climate require actions that range from incremental changes to more fundamental, transformational changes[34]. Mitigation can involve fundamental changes in the way that human societies produce and use energy services and land. *{WGII B, C, TS C, Box TS.8, Glossary, WGIII SPM.4}*

Topic 3 of this report examines the factors that influence the assessment of mitigation and adaptation strategies. It considers the benefits, risks, incremental changes and potential transformations from different combinations of mitigation, adaptation and residual climate-related impacts. It considers how responses in the coming decades will influence options for limiting long-term climate change and opportunities for adapting to it. Finally, it considers factors—including uncertainty, ethical considerations and links to other societal goals—that may influence choices about mitigation and adaptation. Topic 4 then assesses the prospects for mitigation and adaptation on the basis of current knowledge of tools, options and policies.

3.1 Foundations of decision-making about climate change

Effective decision-making to limit climate change and its effects can be informed by a wide range of analytical approaches for evaluating expected risks and benefits, recognizing the importance of governance, ethical dimensions, equity, value judgments, economic assessments and diverse perceptions and responses to risk and uncertainty.

Sustainable development and equity provide a basis for assessing climate policies. Limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication. Countries' past and future contributions to the accumulation of GHGs in the atmosphere are different, and countries also face varying challenges and circumstances and have different capacities to address mitigation and adaptation. Mitigation and adaptation raise issues of equity, justice and fairness and are necessary to achieve sustainable development and poverty eradication. Many of those most vulnerable to climate change have contributed and contribute little to GHG emissions. Delaying mitigation shifts burdens from the present to the future, and insufficient adaptation responses to emerging impacts are already eroding the basis for sustainable development. Both adaptation and mitigation can have distributional effects locally, nationally and internationally, depending on who pays and who benefits. The process of decision-making about climate change, and the degree to which it respects the rights and views of all those affected, is also a concern of justice. *{WGII 2.2, 2.3, 13.3, 13.4, 17.3, 20.2, 20.5, WGIII SPM.2, 3.3, 3.10, 4.1.2, 4.2, 4.3, 4.5, 4.6, 4.8}*

Effective mitigation will not be achieved if individual agents advance their own interests independently. Climate change has the characteristics of a collective action problem at the global scale, because most GHGs accumulate over time and mix globally, and emissions by any agent (e.g., individual, community, company, country) affect other agents. Cooperative responses, including international cooperation, are therefore required to effectively mitigate GHG emissions and address other climate change issues. The effectiveness of adaptation can be enhanced through complementary actions across levels, including international cooperation. The evidence suggests that outcomes seen as equitable can lead to more effective cooperation. *{WGII 20.3.1, WGIII SPM.2, TS.1, 1.2, 2.6, 3.2, 4.2, 13.2, 13.3}*

Decision-making about climate change involves valuation and mediation among diverse values and may be aided by the analytic methods of several normative disciplines. Ethics analyses the different values involved and the relations between them. Recent political philosophy has investigated the question of responsibility for the effects of emissions. Economics and decision analysis provide

[34] Transformation is used in this report to refer to a change in the fundamental attributes of a system (see Glossary). Transformations can occur at multiple levels; at the national level, transformation is considered most effective when it reflects a country's own visions and approaches to achieving sustainable development in accordance with its national circumstances and priorities. *{WGII SPM C-2, 2–13, 20.5, WGIII SPM, 6–12}*

quantitative methods of valuation which can be used for estimating the social cost of carbon (see Box 3.1), in cost–benefit and cost-effectiveness analyses, for optimization in integrated models and elsewhere. Economic methods can reflect ethical principles, and take account of non-marketed goods, equity, behavioural biases, ancillary benefits and costs and the differing values of money to different people. They are, however, subject to well-documented limitations. *{WGII 2.2, 2.3, WGIII SPM.2, Box TS.2, 2.4, 2.5, 2.6, 3.2–3.6, 3.9.4}*

Analytical methods of valuation cannot identify a single best balance between mitigation, adaptation and residual climate impacts. Important reasons for this are that climate change involves extremely complex natural and social processes, there is extensive disagreement about the values concerned, and climate change impacts and mitigation approaches have important distributional effects. Nevertheless, information on the consequences of emissions pathways to alternative climate goals and risk levels can be a useful input into decision-making processes. Evaluating responses to climate change involves assessment of the widest possible range of impacts, including low-probability outcomes with large consequences. *{WGII 1.1.4, 2.3, 2.4, 17.3, 19.6, 19.7, WGIII 2.5, 2.6, 3.4, 3.7, Box 3-9}*

Effective decision-making and risk management in the complex environment of climate change may be iterative: strategies can often be adjusted as new information and understanding develops during implementation. However, adaptation and mitigation choices in the near term will affect the risks of climate change throughout the 21st century and beyond, and prospects for climate-resilient pathways for sustainable development depend on what is achieved through mitigation. Opportunities to take advantage of positive synergies between adaptation and mitigation may decrease with time, particularly if mitigation is delayed too long. Decision-making about climate change is influenced by how individuals and organizations perceive risks and uncertainties and take them into account. They sometimes use simplified decision rules, overestimate or underestimate risks and are biased towards the status quo. They differ in their degree of risk aversion and the relative importance placed on near-term versus long-term ramifications of specific actions. Formalized analytical methods for decision-making under uncertainty can account accurately for risk, and focus attention on both short- and long-term consequences. *{WGII SPM A-3, SPM C-2, 2.1–2.4, 3.6, 14.1–14.3, 15.2–15.4, 17.1–17.3, 17.5, 20.2, 20.3, 20.6, WGIII SPM.2, 2.4, 2.5, 5.5, 16.4}*

3.2 Climate change risks reduced by adaptation and mitigation

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*). Mitigation involves some level of co-benefits and of risks due to adverse side effects, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change, increasing the benefits from near-term mitigation efforts.

The risks of climate change, adaptation and mitigation differ in nature, timescale, magnitude and persistence (*high confidence*). Risks from adaptation include maladaptation and negative ancillary impacts. Risks from mitigation include possible adverse side effects of large-scale deployment of low-carbon technology options and economic costs. Climate change risks may persist for millennia and can involve very high risk of severe impacts and the presence of significant irreversibilities combined with limited adaptive capacity. In contrast, the stringency of climate policies can be adjusted much more quickly in response to observed consequences and costs and create lower risks of irreversible consequences (3.3, 3.4, 4.3). *{WGI SPM E.8, 12.4, 12.5.2, 13.5, WGII 4.2, 17.2, 19.6, WGIII TS.3.1.4, Table TS.4, Table TS.5, Table TS.6, Table TS.7, Table TS.8, 2.5, 6.6}*

Mitigation and adaptation are complementary approaches for reducing risks of climate change impacts. They interact with one another and reduce risks over different timescales (*high confidence*). Benefits from adaptation can already be realized in addressing current risks and can be realized in the future for addressing emerging risks. Adaptation has the potential to reduce climate change impacts over the next few decades, while mitigation has relatively little influence on climate outcomes over this timescale. Near-term and longer-term mitigation and adaptation, as well as development pathways, will determine the risks of climate change beyond mid-century. The potential for adaptation differs across sectors and will be limited by institutional and capacity constraints, increasing the long-term benefits of mitigation (*high confidence*). The level of mitigation will influence the rate and magnitude of climate change, and greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*) (*3.3*). *{WGI 11.3, 12.4, WGII SPM A-3, SPM B-2, SPM C-2, 1.1.4.4, 2.5, 16.3–16.6, 17.3, 19.2, 20.2.3, 20.3, 20.6}*

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*) (Topic 2 and Figure 3.1a). Estimates of warming in 2100 without additional climate mitigation efforts are from 3.7°C to 4.8°C compared with pre-industrial levels (median climate response); the range is 2.5°C to 7.8°C when using the 5th to 95th percentile range of the median climate response (Figure 3.1). The risks associated with temperatures at or above 4°C include severe and widespread impacts on unique and threatened systems, substantial species extinction, large risks to global and regional food security, consequential constraints on common human activities, increased likelihood of triggering tipping points (critical thresholds) and limited potential for adaptation in some cases (*high confidence*). Some risks of climate change, such as risks to unique and threatened systems and risks associated with extreme weather events, are moderate to high at temperatures 1°C to 2°C above pre-industrial levels. *{WGII SPM B-1, SPM C-2, WGIII SPM.3}*

Substantial cuts in GHG emissions over the next few decades can substantially reduce risks of climate change by limiting warming in the second half of the 21st century and beyond (*high confidence*). Global mean surface warming is largely determined by cumulative emissions, which are, in turn, linked to emissions over different timescales (Figure 3.1). Limiting risks across Reasons For Concern would imply a limit for cumulative emissions of CO_2.

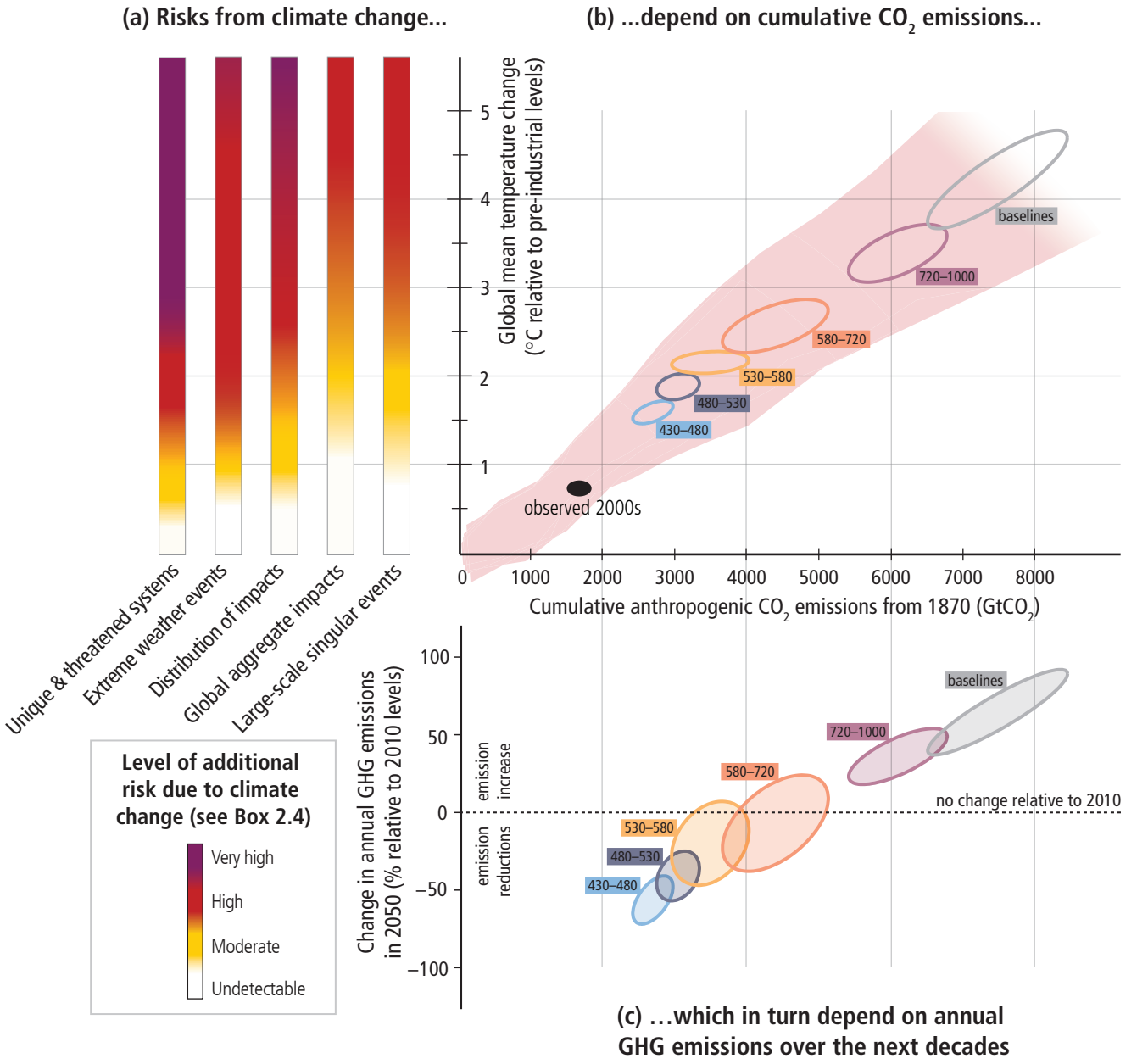


Figure 3.1 | The relationship between risks from climate change, temperature change, cumulative carbon dioxide (CO_2) emissions and changes in annual greenhouse gas (GHG) emissions by 2050. Limiting risks across Reasons For Concern **(a)** would imply a limit for cumulative emissions of CO_2 **(b)**, which would constrain annual emissions over the next few decades **(c)**. **Panel a** reproduces the five Reasons For Concern (Box 2.4). **Panel b** links temperature changes to cumulative CO_2 emissions (in $GtCO_2$), from 1870. They are based on Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations (pink plume) and on a simple climate model (median climate response in 2100) for the baselines and five mitigation scenario categories (six ellipses). Details are provided in Figure 2.3. **Panel c** shows the relationship between the cumulative CO_2 emissions (in $GtCO_2$) of the scenario categories and their associated change in annual GHG emissions by 2050, expressed in percentage change (in percent $GtCO_2$-eq per year) relative to 2010. The ellipses correspond to the same scenario categories as in Panel b, and are built with a similar method (see details in Figure 2.3).

Such a limit would require that global net emissions of CO_2 eventually decrease to zero (Figure 3.1a,b) (*high confidence*). Reducing risks of climate change through mitigation would involve substantial cuts in GHG emissions over the next few decades (Figure 3.1c). But some risks from residual damages are unavoidable, even with mitigation and adaptation (*very high confidence*). A subset of relevant climate change risks has been estimated using aggregate economic indicators. Such economic estimates have important limitations and are therefore a useful but insufficient basis for decision-making on long-term mitigation targets (see Box 3.1). *{WGII 19.7.1, WGIII SPM.3, Figure 3.1}*

Mitigation involves some level of co-benefits and risks, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change (*high confidence*). Scenarios that are *likely* to limit warming to below 2°C or even 3°C compared with pre-industrial temperatures involve large-scale changes in energy systems and potentially land use over the coming decades (3.4). Associated risks include those linked to large-scale deployment of technology options for producing low-carbon energy, the potential for high aggregate economic costs of mitigation and impacts on vulnerable countries and industries. Other risks and co-benefits are associated with human health, food security, energy security, poverty

reduction, biodiversity conservation, water availability, income distribution, efficiency of taxation systems, labour supply and employment, urban sprawl, fossil fuel export revenues and the economic growth of developing countries (Table 4.5). *{WGIII SPM.4.1, SPM.4.2, TS.3.1.4, Table TS.4, Table TS.5, Table TS.6, Table TS.7, Table TS.8, 6.6}*

Inertia in the economic and climate systems and the possibility of irreversible impacts from climate change increase the benefits of near-term mitigation efforts (*high confidence*). The actions taken today affect the options available in the future to reduce emissions, limit temperature change and adapt to climate change. Near-term choices can create, amplify or limit significant elements of lock-in that are important for decision-making. Lock-ins and irreversibilities occur in the climate system due to large inertia in some of its components such as heat transfer from the ocean surface to depth leading to continued ocean warming for centuries regardless of emission scenario and the irreversibility of a large fraction of anthropogenic climate change resulting from CO_2 emissions on a multi-century to millennial timescale unless CO_2 were to be removed from the atmosphere through large-scale human interventions over a sustained period (see also Box 3.3). Irreversibilities in socio-economic and biological systems also result from infrastructure development and long-lived products and from climate change impacts, such as species extinction. The larger potential for irreversibility and pervasive impacts from climate change risks than from mitigation risks increases the benefit of short-term mitigation efforts. Delays in additional mitigation or constraints on technological options limit the mitigation options and increase the long-term mitigation costs as well as other risks that would be incurred in the medium to long term to hold climate change impacts at a given level (Table WGIII SPM.2, blue segment). *{WGI SPM E-8, WGII SPM B-2, 2.1, 19.7, 20.3, Box 20-4, WGIII SPM.4.1, SPM.4.2.1, 3.6, 6.4, 6.6, 6.9}*

3.3 Characteristics of adaptation pathways

Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, especially with greater magnitudes and rates of climate change. Taking a longer-term perspective, in the context of sustainable development, increases the likelihood that more immediate adaptation actions will also enhance future options and preparedness.

Adaptation can contribute to the well-being of current and future populations, the security of assets and the maintenance of ecosystem goods, functions and services now and in the future. Adaptation is place- and context-specific, with no single approach for reducing risks appropriate across all settings (*high confidence*). Effective risk reduction and adaptation strategies consider vulnerability and exposure and their linkages with socio-economic processes, sustainable development, and climate change. Adaptation research since the IPCC Fourth Assessment Report (AR4) has evolved from a dominant consideration of engineering and technological adaptation pathways to include more ecosystem-based, institutional and social measures. A previous focus on cost–benefit analysis, optimization and efficiency approaches has broadened with the development of multi-metric evaluations that include risk and uncertainty dimensions integrated within wider policy and ethical frameworks to assess trade-offs and constraints. The range of specific adaptation measures has also expanded (4.2, 4.4.2.1), as have the links to sustainable development (3.5). There are many studies on local and sectoral adaptation costs and benefits, but few global analyses and *very low confidence*

Box 3.1 | The Limits of the Economic Assessment of Climate Change Risks

A subset of climate change risks and impacts are often measured using aggregate economic indicators, such as gross domestic product (GDP) or aggregate income. Estimates, however, are partial and affected by important conceptual and empirical limitations. These incomplete estimates of global annual economic losses for temperature increases of ~2.5°C above pre-industrial levels are between 0.2 and 2.0% of income (*medium evidence, medium agreement*). Losses are *more likely than not* to be greater, rather than smaller, than this range (*limited evidence, high agreement*). Estimates of the incremental aggregate economic impact of emitting one more tonne of carbon dioxide (the social cost of carbon) are derived from these studies and lie between a few dollars and several hundreds of dollars per tonne of carbon in 2000 to 2015 (*robust evidence, medium agreement*). These impact estimates are incomplete and depend on a large number of assumptions, many of which are disputable. Many estimates do not account for the possibility of large-scale singular events and irreversibility, tipping points and other important factors, especially those that are difficult to monetize, such as loss of biodiversity. Estimates of aggregate costs mask significant differences in impacts across sectors, regions, countries and communities, and they therefore depend on ethical considerations, especially on the aggregation of losses across and within countries (*high confidence*). Estimates of global aggregate economic losses exist only for limited warming levels. These levels are exceeded in scenarios for the 21st century unless additional mitigation action is implemented, leading to additional economic costs. The total economic effects at different temperature levels would include mitigation costs, co-benefits of mitigation, adverse side effects of mitigation, adaptation costs and climate damages. As a result, mitigation cost and climate damage estimates at any given temperature level cannot be compared to evaluate the costs and benefits of mitigation. Very little is known about the economic cost of warming above 3°C relative to the current temperature level. Accurately estimating climate change risks (and thus the benefits of mitigation) takes into account the full range of possible impacts of climate change, including those with high consequences but a low probability of occurrence. The benefits of mitigation may otherwise be underestimated (*high confidence*). Some limitations of current estimates may be unavoidable, even with more knowledge, such as issues with aggregating impacts over time and across individuals when values are heterogeneous. In view of these limitations, it is outside the scope of science to identify a single best climate change target and climate policy (3.1, 3.4). *{WGII SPM B-2, 10.9.2, 10.9.4, 13.2, 17.2–17.3, 18.4, 19.6, WGIII 3.6}*

in their results. *{WGII SPM C-1, Table SPM.1, 14.1, 14.ES, 15.2, 15.5, 17.2, 17.ES}*

Adaptation planning and implementation at all levels of governance are contingent on societal values, objectives and risk perceptions (*high confidence*). Recognition of diverse interests, circumstances, social-cultural contexts and expectations can benefit decision-making processes. Indigenous, local and traditional knowledge systems and practices, including indigenous peoples' holistic view of community and environment, are a major resource for adapting to climate change, but these have not been used consistently in existing adaptation efforts. Integrating such forms of knowledge into practices increases the effectiveness of adaptation as do effective decision support, engagement and policy processes (4.4.2). *{WGII SPM C-1}*

Adaptation planning and implementation can be enhanced through complementary actions across levels, from individuals to governments (*high confidence*). National governments can coordinate adaptation efforts of local and sub-national governments, for example by protecting vulnerable groups, by supporting economic diversification and by providing information, policy and legal frameworks and financial support (*robust evidence, high agreement*). Local government and the private sector are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing (*medium evidence, high agreement*). *{WGII SPM C-1}*

A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability (*high confidence*), but some near-term responses to climate change may also limit future choices. Integration of adaptation into planning, including policy design, and decision-making can promote synergies with development and disaster risk reduction. However, poor planning or implementation, overemphasizing short-term outcomes or failing to sufficiently anticipate consequences can result in maladaptation, increasing the vulnerability or exposure of the target group in the future or the vulnerability of other people, places or sectors (*medium evidence, high agreement*). For example, enhanced protection of exposed assets can lock in dependence on further protection measures. Appropriate adaptation options can be better assessed by including co-benefits and mitigation implications (3.5 and 4.2). *{WGII SPM C-1}*

Numerous interacting constraints can impede adaptation planning and implementation (*high confidence*). Common constraints on implementation arise from the following: limited financial and human resources; limited integration or coordination of governance; uncertainties about projected impacts; different perceptions of risks; competing values; absence of key adaptation leaders and advocates; and limited tools to monitor adaptation effectiveness. Other constraints include insufficient research, monitoring and observation and the financial and other resources to maintain them. Underestimating the complexity of adaptation as a social process can create unrealistic expectations about achieving intended adaptation outcomes (see Sections 4.1 and 4.2 for details in relation to implementation). *{WGII SPM C-1}*

Greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*). Limits to adaptation occur when adaptive actions to avoid intolerable risks for an actor's objectives or for the needs of a system are not possible or are not currently available. Value-based judgments of what constitutes an intolerable risk may differ. Limits to adaptation emerge from the interaction among climate change and biophysical and/or socio-economic constraints. Opportunities to take advantage of positive synergies between adaptation and mitigation may decrease with time, particularly if limits to adaptation are exceeded. In some parts of the world, insufficient responses to emerging impacts are already eroding the basis for sustainable development. For most regions and sectors, empirical evidence is not sufficient to quantify magnitudes of climate change that would constitute a future adaptation limit. Furthermore, economic development, technology and cultural norms and values can change over time to enhance or reduce the capacity of systems to avoid limits. As a consequence, some limits are 'soft' in that they may be alleviated over time. Other limits are 'hard' in that there are no reasonable prospects for avoiding intolerable risks. *{WGII SPM C-2, TS}*

Transformations in economic, social, technological and political decisions and actions can enhance adaptation and promote sustainable development (*high confidence*). Restricting adaptation responses to incremental changes to existing systems and structures without considering transformational change may increase costs and losses and miss opportunities. For example, enhancing infrastructure to protect other built assets can be expensive and ultimately not defray increasing costs and risks, whereas options such as relocation or using ecosystem services to adapt may provide a range of benefits now and in the future. Transformational adaptation can include introduction of new technologies or practices, formation of new financial structures or systems of governance, adaptation at greater scales or magnitudes and shifts in the location of activities. Planning and implementation of transformational adaptation could reflect strengthened, altered or aligned paradigms and consequently may place new and increased demands on governance structures to reconcile different goals and visions for the future and to address possible equity and ethical implications: transformational adaptation pathways are enhanced by iterative learning, deliberative processes, and innovation. At the national level, transformation is considered most effective when it reflects a country's own visions and approaches to achieving sustainable development in accordance with its national circumstances and priorities. *{WGII SPM C-2, 1.1, 2.5, 5.5, 8.4, 14.1, 14.3, 16.2-7, 20.3.3, 20.5, 25.10, Table 14-4, Table 16-3, Box 16.1, Box 16.4, Box 25.1}*

Building adaptive capacity is crucial for effective selection and implementation of adaptation options (*robust evidence, high agreement*). Successful adaptation requires not only identifying adaptation options and assessing their costs and benefits, but also increasing the adaptive capacity of human and natural systems (*medium evidence, high agreement*). This can involve complex governance challenges and new institutions and institutional arrangements. (4.2) *{WGII 8.1, 12.3, 14.1-3, 16.2, 16.3, 16.5, 16.8}*

Significant co-benefits, synergies and trade-offs exist between mitigation and adaptation and among different adaptation responses; interactions occur both within and across regions (*very high confidence*). Increasing efforts to mitigate and adapt to climate

change imply an increasing complexity of interactions, particularly at the intersections among water, energy, land use and biodiversity, but tools to understand and manage these interactions remain limited. Examples of actions with co-benefits include (i) improved energy efficiency and cleaner energy sources, leading to reduced emissions of health-damaging, climate-altering air pollutants; (ii) reduced energy and water consumption in urban areas through greening cities and recycling water; (iii) sustainable agriculture and forestry; and (iv) protection of ecosystems for carbon storage and other ecosystem services. *{WGII SPM C-1}*

3.4 Characteristics of mitigation pathways

There are multiple mitigation pathways that are *likely* to limit warming to below 2°C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of CO_2 and other long-lived greenhouse gases by the end of the century. Implementing such reductions poses substantial technological, economic, social and institutional challenges, which increase with delays in additional mitigation and if key technologies are not available. Limiting warming to lower or higher levels involves similar challenges but on different timescales.

Without additional efforts to reduce GHG emissions beyond those in place today, global emission growth is expected to persist driven by growth in global population and economic activities (*high confidence*) (Figure 3.2). Global GHG emissions under most scenarios without additional mitigation (baseline scenarios) are between about 75 $GtCO_2$-eq/yr and almost 140 $GtCO_2$-eq/yr in 2100[35] which is approximately between the 2100 emission levels in the RCP6.0 and RCP8.5 pathways (Figure 3.2)[36]. Baseline scenarios exceed 450 ppm CO_2-eq by 2030 and reach CO_2-eq concentration levels between about 750 ppm CO_2-eq and more than 1300 ppm CO_2-eq by 2100. Global mean surface temperature increases in 2100 range from about 3.7°C to 4.8°C above the average for 1850–1900 for a median climate response. They range from 2.5°C to 7.8°C when including climate uncertainty (5th to 95th percentile range)[37]. The future scenarios do not account for possible changes in natural forcings in the climate system (see Box 1.1). *{WGIII SPM.3, SPM.4.1, TS.2.2, TS.3.1, 6.3, Box TS.6}*

Many different combinations of technological, behavioural and policy options can be used to reduce emissions and limit temperature change (*high confidence*). To evaluate possible pathways to long-term climate goals, about 900 mitigation scenarios were collected for this assessment, each of which describes different technological, socio-economic and institutional changes. Emission reductions under these scenarios lead to concentrations in 2100 from 430 ppm CO_2-eq to above 720 ppm CO_2-eq which is comparable to the 2100 forcing levels between RCP2.6 and RCP6.0. Scenarios with concentration levels of below 430 ppm CO_2-eq by 2100 were also assessed. *{WGIII SPM.4.1, TS3.1, 6.1, 6.2, 6.3, Annex II}*

Scenarios leading to CO_2-eq concentrations in 2100 of about 450 ppm or lower are *likely* to maintain warming below 2°C over the 21st century relative to pre-industrial levels (*high confidence*). Mitigation scenarios reaching concentration levels of about 500 ppm CO_2-eq by 2100 are *more likely than not* to limit warming to less than 2°C relative to pre-industrial levels, unless concentration levels temporarily exceed roughly 530 ppm CO_2-eq before 2100. In this case, warming is *about as likely as not* to remain below 2°C relative to pre-industrial levels. Scenarios that exceed about 650 ppm CO_2-eq by 2100 are *unlikely* to limit warming to below 2°C relative to pre-industrial levels. Mitigation scenarios in which warming is *more likely than not* to be less than 1.5°C relative to pre-industrial levels by 2100 are characterized by concentration levels by 2100 of below 430 ppm CO_2-eq. In these scenarios, temperature peaks during the century and subsequently declines (Table 3.1). *{WGIII SPM.4.1, Table SPM.1, TS.3.1, Box TS.6, 6.3}*

Mitigation scenarios reaching about 450 ppm CO_2-eq in 2100 (consistent with a *likely* chance to keep warming below 2°C relative to pre-industrial level) typically involve temporary overshoot[38] of atmospheric concentrations, as do many scenarios reaching about 500 ppm CO_2-eq to about 550 ppm CO_2-eq by 2100 (Table 3.1). Depending on the level of overshoot, overshoot scenarios typically rely on the availability and widespread deployment of bioenergy with carbon dioxide capture and storage (BECCS) and afforestation in the second half of the century (*high confidence*). The availability and scale of these and other Carbon Dioxide Removal (CDR) technologies and methods are uncertain, and CDR technologies and methods are, to varying degrees, associated with challenges and risks (see Box 3.3)[39]. CDR is also prevalent in many scenarios without overshoot to compensate for residual emissions from sectors where mitigation is more expensive. *{WGIII SPM.4.1, Table SPM.1, TS.3.1, 6.3, 6.9.1, Figure 6.7, 7.11, 11.13}*

[35] Unless otherwise noted, scenario ranges cited in Topic 3 and Topic 4 refer to the 10th to 90th percentile ranges (see Table 3.1).

[36] For a discussion on CO2-equivalent (CO2-eq) emissions and concentrations, see Box 3.2 on GHG metrics and mitigation pathways and the Glossary.

[37] The range quoted here is based on the warming results of a simple climate model for the emissions of around 300 baseline scenarios, expressed compared to the 1850–1900 period. The warming results quoted in Section 2.2 are obtained by prescribing future concentrations of GHG in CMIP5 Earth System Models. This results in a mean warming of 1.0°C (5th to 95th percentile range: 0.3°C to 1.7°C) for RCP2.6, and a mean warming of 3.7°C (2.6°C to 4.8°C) for RCP8.5 relative to the period 1986–2005. For the same concentration-driven experiments, the simple climate model approach gives consistent results. The median warming is 0.9°C (0.5°C to 1.6°C) for RCP2.6 and 3.7°C (2.5°C to 5.9°C) for RCP8.5 relative to the period 1986–2005. However, the high-end of the CMIP5 ESMs range is more constrained. In addition, the baseline temperature increase quoted here is wider than that of the concentration-driven RCP8.5 experiments mentioned above as it is based on a wider set of scenarios, includes carbon cycle response uncertainty, and uses a different base year (2.2, 3.4).

[38] In concentration 'overshoot' scenarios, concentrations peak during the century and then decline.

[39] CDR methods have biogeochemical and technological limitations to their potential on the global scale. There is insufficient knowledge to quantify how much CO2 emissions could be partially offset by CDR on a century timescale. CDR methods may carry side effects and long-term consequences on a global scale.

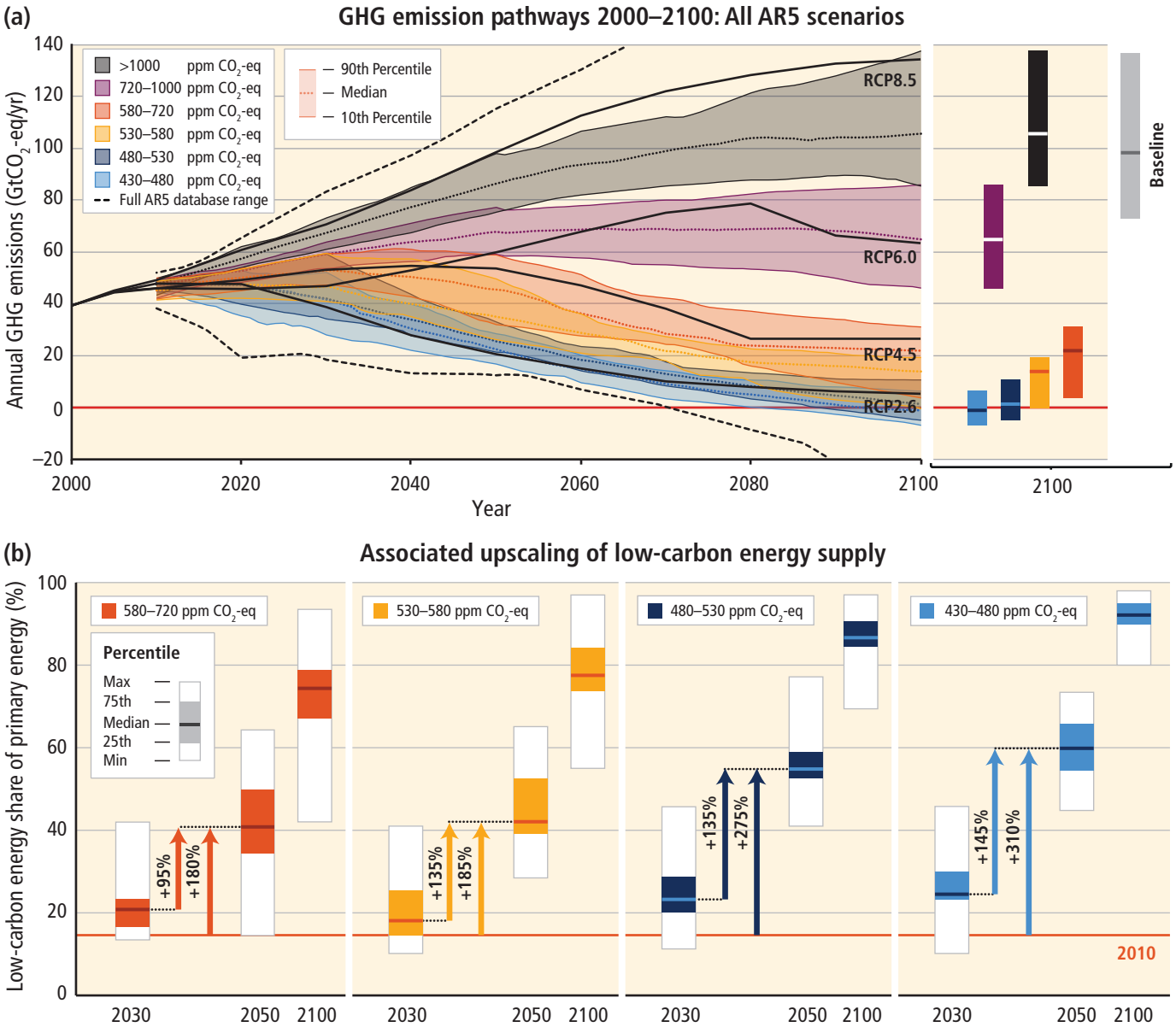


Figure 3.2 | Global greenhouse gas (GHG) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) in baseline and mitigation scenarios for different long-term concentration levels **(a)** and associated scale-up requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100, compared to 2010 levels, in mitigation scenarios **(b)**. *{WGIII SPM.4, Figure 6.7, Figure 7.16}* [Note: CO_2-eq emissions include the basket of Kyoto gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) as well as fluorinated gases) calculated based on 100-year Global Warming Potential (GWP_{100}) values from the IPCC Second Assessment Report.]

Limiting warming with a *likely* chance to less than 2°C relative to pre-industrial levels would require substantial cuts in anthropogenic GHG emissions[40] by mid-century through large-scale changes in energy systems and possibly land use. Limiting warming to higher levels would require similar changes but less quickly. Limiting warming to lower levels would require these changes more quickly (*high confidence*). Scenarios that are *likely* to maintain warming at below 2°C are characterized by a 40 to 70% reduction in GHG emissions by 2050, relative to 2010 levels, and emissions levels near zero or below in 2100 (Figure 3.2, Table 3.1). Scenarios with higher emissions in 2050 are characterized by a greater reliance on CDR technologies beyond mid-century, and vice versa. Scenarios that are *likely* to maintain warming at below 2°C include more rapid improvements in energy efficiency and a tripling to nearly a quadrupling of the share of zero- and low-carbon energy supply from renewable energy, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS) or BECCS by the year 2050 (Figure 3.2b). The scenarios describe a wide range of changes in land use, reflecting

[40] This range differs from the range provided for a similar concentration category in AR4 (50 to 85% lower than in 2000 for CO_2 only). Reasons for this difference include that this report has assessed a substantially larger number of scenarios than in AR4 and looks at all GHGs. In addition, a large proportion of the new scenarios include CDR technologies. Other factors include the use of 2100 concentration levels instead of stabilization levels and the shift in reference year from 2000 to 2010. Scenarios with higher emission levels by 2050 are characterized by a greater reliance on CDR technologies beyond mid-century.

Table 3.1 | Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters the 10th to 90th percentile of the scenarios is shown [a].

CO_2-eq Concentrations in 2100 (ppm CO_2-eq) [f] Category label (conc. range)	Subcategories	Relative position of the RCPs [d]	Change in CO_2-eq emissions compared to 2010 (in %) [c]		Likelihood of staying below a specific temperature level over the 21st century (relative to 1850–1900) [d, e]			
			2050	2100	1.5°C	2°C	3°C	4°C
<430	Only a limited number of individual model studies have explored levels below 430 ppm CO_2-eq [j]							
450 (430 to 480)	Total range [a, g]	RCP2.6	–72 to –41	–118 to –78	*More unlikely than likely*	*Likely*	*Likely*	*Likely*
500 (480 to 530)	No overshoot of 530 ppm CO_2-eq		–57 to –42	–107 to –73	*Unlikely*	*More likely than not*		
	Overshoot of 530 ppm CO_2-eq		–55 to –25	–114 to –90		*About as likely as not*		
550 (530 to 580)	No overshoot of 580 ppm CO_2-eq		–47 to –19	–81 to –59		*More unlikely than likely* [i]		
	Overshoot of 580 ppm CO_2-eq		–16 to 7	–183 to –86				
(580 to 650)	Total range	RCP4.5	–38 to 24	–134 to –50				
(650 to 720)	Total range		–11 to 17	–54 to –21		*Unlikely*	*More likely than not*	
(720 to 1000) [b]	Total range	RCP6.0	18 to 54	–7 to 72	*Unlikely* [h]		*More unlikely than likely*	
>1000 [b]	Total range	RCP8.5	52 to 95	74 to 178		*Unlikely* [h]	*Unlikely*	*More unlikely than likely*

Notes:

[a] The 'total range' for the 430 to 480 ppm CO_2-eq concentrations scenarios corresponds to the range of the 10th to 90th percentile of the subcategory of these scenarios shown in Table 6.3 of the Working Group III report.

[b] Baseline scenarios fall into the >1000 and 720 to 1000 ppm CO_2-eq categories. The latter category also includes mitigation scenarios. The baseline scenarios in the latter category reach a temperature change of 2.5°C to 5.8°C above the average for 1850–1900 in 2100. Together with the baseline scenarios in the >1000 ppm CO_2-eq category, this leads to an overall 2100 temperature range of 2.5°C to 7.8°C (range based on median climate response: 3.7°C to 4.8°C) for baseline scenarios across both concentration categories.

[c] The global 2010 emissions are 31% above the 1990 emissions (consistent with the historic greenhouse gas emission estimates presented in this report). CO_2-eq emissions include the basket of Kyoto gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) as well as fluorinated gases).

[d] The assessment here involves a large number of scenarios published in the scientific literature and is thus not limited to the Representative Concentration Pathways (RCPs). To evaluate the CO_2-eq concentration and climate implications of these scenarios, the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) was used in a probabilistic mode. For a comparison between MAGICC model results and the outcomes of the models used in WGI, see WGI 12.4.1.2, 12.4.8 and WGIII 6.3.2.6.

[e] The assessment in this table is based on the probabilities calculated for the full ensemble of scenarios in WGIII using MAGICC and the assessment in WGI of the uncertainty of the temperature projections not covered by climate models. The statements are therefore consistent with the statements in WGI, which are based on the Coupled Model Intercomparison Project Phase 5 (CMIP5) runs of the RCPs and the assessed uncertainties. Hence, the likelihood statements reflect different lines of evidence from both WGs. This WGI method was also applied for scenarios with intermediate concentration levels where no CMIP5 runs are available. The likelihood statements are indicative only *{WGIII 6.3}* and follow broadly the terms used by the WGI SPM for temperature projections: likely 66–100%, more likely than not >50–100%, about as likely as not 33–66%, and unlikely 0–33%. In addition the term more unlikely than likely 0–<50% is used.

[f] The CO_2-equivalent concentration (see Glossary) is calculated on the basis of the total forcing from a simple carbon cycle/climate model, MAGICC. The CO_2-equivalent concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 to 520 ppm). This is based on the assessment of total anthropogenic radiative forcing for 2011 relative to 1750 in WGI, i.e., 2.3 W/m^2, uncertainty range 1.1 to 3.3 W/m^2.

[g] The vast majority of scenarios in this category overshoot the category boundary of 480 ppm CO_2-eq concentration.

[h] For scenarios in this category, no CMIP5 run or MAGICC realization stays below the respective temperature level. Still, an *unlikely* assignment is given to reflect uncertainties that may not be reflected by the current climate models.

[i] Scenarios in the 580 to 650 ppm CO_2-eq category include both overshoot scenarios and scenarios that do not exceed the concentration level at the high end of the category (e.g., RCP4.5). The latter type of scenarios, in general, have an assessed probability of *more unlikely than likely* to stay below the 2°C temperature level, while the former are mostly assessed to have an *unlikely* probability of staying below this level.

[j] In these scenarios, global CO_2-eq emissions in 2050 are between 70 to 95% below 2010 emissions, and they are between 110 to 120% below 2010 emissions in 2100.

different assumptions about the scale of bioenergy production, afforestation and reduced deforestation. Scenarios leading to concentrations of 500 ppm CO_2-eq by 2100 are characterized by a 25 to 55% reduction in GHG emissions by 2050, relative to 2010 levels. Scenarios that are *likely* to limit warming to 3°C relative to pre-industrial levels reduce emissions less rapidly than those limiting warming to 2°C. Only a limited number of studies provide scenarios that are *more likely than not* to limit warming to 1.5°C by 2100; these scenarios are characterized by concentrations below 430 ppm CO_2-eq by 2100 and 2050 emission reduction between 70 and 95% below 2010. For a comprehensive overview of the characteristics of emissions scenarios, their CO_2-equivalent concentrations and their likelihood to keep warming to below a range of temperature levels, see Table 3.1. *{WGIII SPM.4.1, TS.3.1, 6.3, 7.11}*

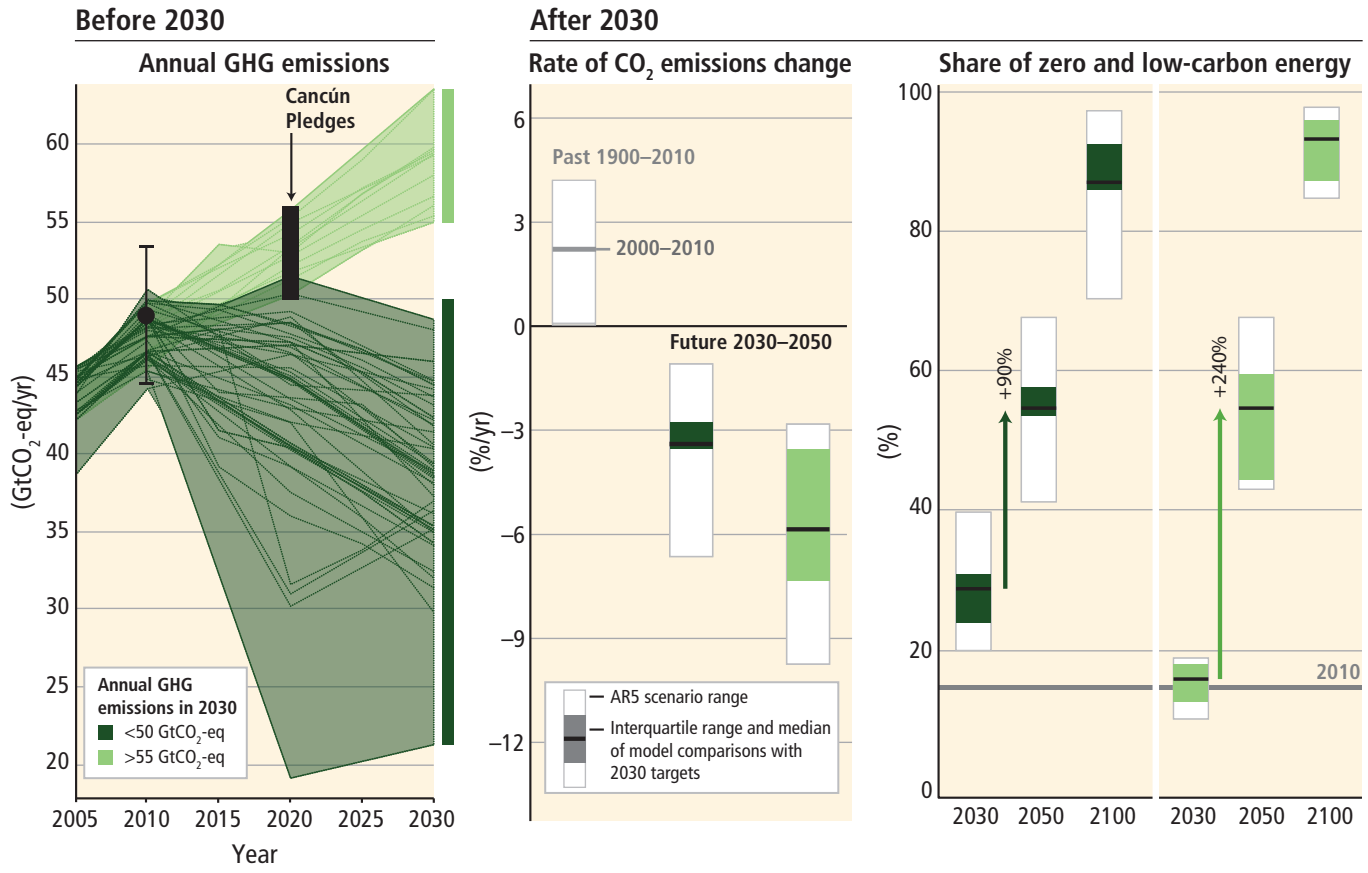


Figure 3.3 | The implications of different 2030 greenhouse gas (GHG) emissions levels for the rate of carbon dioxide (CO_2) emission reductions and low-carbon energy upscaling in mitigation scenarios that are at least *about as likely as not* to keep warming throughout the 21st century below 2°C relative to pre-industrial levels (2100 CO_2-eq concentrations 430 to 530 ppm). The scenarios are grouped according to different emissions levels by 2030 (coloured in different shades of green). The left panel shows the pathways of GHG emissions ($GtCO_2$-eq/yr) leading to these 2030 levels. Black dot with whiskers gives historic GHG emission levels and associated uncertainties in 2010 as reported in Figure 1.6. The black bar shows the estimated uncertainty range of GHG emissions implied by the Cancún Pledges. The middle panel denotes the average annual CO_2 emission reduction rates for the 2030–2050 period. It compares the median and interquartile range across scenarios from recent intermodel comparisons with explicit 2030 interim goals to the range of scenarios in the Scenario Database for WGIII AR5. Annual rates of historical emission changes (sustained over a period of 20 years) are shown as well. The arrows in the right panel show the magnitude of zero and low-carbon energy supply upscaling from between 2030 and 2050, subject to different 2030 GHG emission levels. Zero- and low-carbon energy supply includes renewable energy, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS) or bioenergy with CCS (BECCS). Only scenarios that apply the full, unconstrained mitigation technology portfolio of the underlying models (default technology assumption) are shown. Scenarios with large net negative global emissions (>20 $GtCO_2$-eq/yr), scenarios with exogenous carbon price assumptions, and scenarios with 2010 emission levels that are significantly outside the historical range are excluded. *{WGIII Figure SPM.5, Figure 6.32, Figure 7.16, 13.13.1.3}*

Reducing emissions of non-CO_2 climate forcing agents can be an important element of mitigation strategies. Emissions of non-CO_2 gases (methane (CH_4), nitrous oxide (N_2O), and fluorinated gases) contributed about 27% to the total emissions of Kyoto gases in 2010. For most non-CO_2 gases, near-term, low-cost options are available to reduce their emissions. However, some sources of these non-CO_2 gases are difficult to mitigate, such as N_2O emissions from fertilizer use and CH_4 emissions from livestock. As a result, emissions of most non-CO_2 gases will not be reduced to zero, even under stringent mitigation scenarios (see Figure 4.1). The differences in radiative properties and lifetimes of CO_2 and non-CO_2 climate forcing agents have important implications for mitigation strategies (see also Box 3.2). *{WGIII 6.3.2}*

All current GHG emissions and other climate forcing agents affect the rate and magnitude of climate change over the next few decades. Reducing the emissions of certain short-lived climate forcing agents can reduce the rate of warming in the short term but will have only a limited effect on long-term warming, which is driven mainly by CO_2 emissions. There are large uncertainties related to the climate impacts of some of the short-lived climate forcing agents. Although the effects of CH_4 emissions are well understood, there are large uncertainties related to the effects of black carbon. Co-emitted components with cooling effects may further complicate and reduce the climate impacts of emission reductions. Reducing emissions of sulfur dioxide (SO_2) would cause warming. Near-term reductions in short-lived climate forcing agents can have a relatively fast impact on climate change and possible co-benefits for air pollution. *{WGI 8.2.3, 8.3.2, 8.3.4, 8.5.1, 8.7.2, FAQ 8.2, 12.5, WGIII 6.6.2.1}*

Delaying additional mitigation to 2030 will substantially increase the challenges associated with limiting warming over the 21st century to below 2°C relative to pre-industrial levels (*high confidence*). GHG emissions in 2030 lie between about 30 $GtCO_2$-eq/yr and 50 $GtCO_2$-eq/yr in cost-effective scenarios that are *likely* to *about as likely as not* to limit warming to less than 2°C this century relative to pre-industrial levels (2100 atmospheric concentration

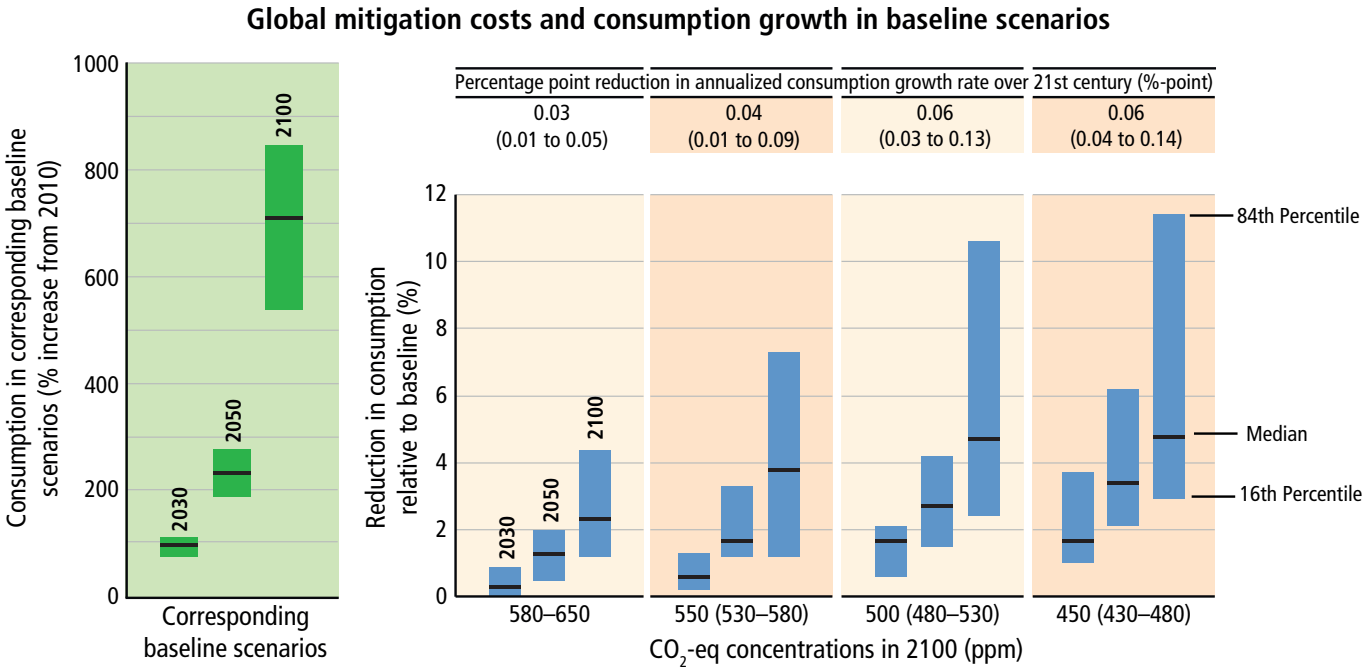


Figure 3.4 | Global mitigation costs in cost-effective scenarios at different atmospheric concentrations levels in 2100 (right panel) and growth in economic consumption in the corresponding baseline scenarios (those without additional mitigation) (left panel). The table at the top shows percentage points of annualized consumption growth reductions relative to consumption growth in the baseline of 1.6 to 3% per year (e.g., if the reduction is 0.06 percentage points per year due to mitigation, and baseline growth is 2.0% per year, then the growth rate with mitigation would be 1.94% per year). Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and they impose no additional limitations on technology relative to the models' default technology assumptions. Consumption losses are shown relative to a baseline development without climate policy. Cost estimates shown in this table do not consider the benefits of reduced climate change nor co-benefits and adverse side effects of mitigation. Estimates at the high end of these cost ranges are from models that are relatively inflexible to achieve the deep emissions reductions that would be required in the long run to meet these goals and/or include assumptions about market imperfections that would raise costs. *{WGIII Table SPM.2, Figure TS.12, 6.3.6, Figure 6.21}*

levels of about 450 ppm CO_2-eq to about 500 ppm CO_2-eq) (Figure 3.3, left panel). Scenarios with GHG emission levels of above 55 $GtCO_2$-eq/yr require substantially higher rates of emissions reductions between 2030 and 2050 (median estimate of 6%/yr as compared to 3%/yr in cost-effective scenarios; Figure 3.3, middle panel); much more rapid scale-up of zero and low-carbon energy over this period (more than a tripling compared to a doubling of the low-carbon energy share relative to 2010; Figure 3.3, right panel); a larger reliance on CDR technologies in the long term; and higher transitional and long-term economic impacts (Table 3.2). (3.5, 4.3) *{WGIII SPM.4.1, TS.3.1, 6.4, 7.11}*

Estimated global emission levels by 2020 based on the Cancún Pledges are not consistent with cost-effective long-term mitigation trajectories that are at least *about as likely as not* to limit warming to below 2°C relative to pre-industrial levels (2100 concentration levels of about 500 ppm CO_2-eq or below), but they do not preclude the option to meet this goal (*high confidence*). The Cancún Pledges are broadly consistent with cost-effective scenarios that are *likely* to limit temperature change to below 3°C relative to pre-industrial levels. *{WGIII SPM.4.1, 6.4, 13.13, Figure TS.11}*

Estimates of the aggregate economic costs of mitigation vary widely depending on methodologies and assumptions but increase with the stringency of mitigation (*high confidence*). Scenarios in which all countries of the world begin mitigation immediately, in which there is a single global carbon price, and in which all key technologies are available have been used as a cost-effective benchmark for estimating macroeconomic mitigation costs (Figure 3.4). Under these assumptions, mitigation scenarios that are *likely* to limit warming to below 2°C through the 21st century relative to pre-industrial levels entail losses in global consumption—not including benefits of reduced climate change (3.2) as well as co-benefits and adverse side effects of mitigation (3.5, 4.3)—of 1 to 4% (median: 1.7%) in 2030, 2 to 6% (median: 3.4%) in 2050, and 3% to 11% (median: 4.8%) in 2100, relative to consumption in baseline scenarios that grows anywhere from 300% to more than 900% over the century[41]. These numbers correspond to an annualized reduction of consumption growth by 0.04 to 0.14 (median: 0.06) percentage points over the century relative to annualized consumption growth in the baseline that is between 1.6% and 3% per year (Figure 3.4). In the absence or under limited availability of mitigation technologies (such as bioenergy, CCS, and their combination BECCS, nuclear, wind and solar), mitigation costs can increase substantially depending on the technology considered (Table 3.2). Delaying additional mitigation reduces near-term costs but increases mitigation costs in the medium- to long-term (Table 3.2). Many models could not limit *likely* warming to below 2°C over the 21st century relative to pre-industrial levels, if additional mitigation is considerably delayed, or if availability of key technologies, such as bioenergy, CCS and their combination (BECCS) are limited (*high confidence*) (Table 3.2). *{WGIII SPM.4.1, Table SPM.2, Table TS.2, TS.3.1, 6.3, 6.6}*

[41] Mitigation cost ranges cited here refer to the 16th to 84th percentile of the underlying sample (see Figure 3.4).

Mitigation efforts and associated cost are expected to vary across countries. The distribution of costs can differ from the distribution of the actions themselves (*high confidence*). In globally cost-effective scenarios, the majority of mitigation efforts takes place in countries with the highest future GHG emissions in baseline scenarios. Some studies exploring particular effort-sharing frameworks, under the assumption of a global carbon market, have estimated substantial global financial flows associated with mitigation in scenarios that are *likely* to *more unlikely than likely* to limit warming during the 21st century to less than 2°C relative to pre-industrial levels. *{WGIII SPM.4.1, TS.3.1, Box 3.5, 4.6, 6.3.6, Table 6.4, Figure 6.9, Figure 6.27, Figure 6.28, Figure 6.29, 13.4.2.4}*

Table 3.2 | Increase in global mitigation costs due to either limited availability of specific technologies or delays in additional mitigation [a] relative to cost-effective scenarios [b]. The increase in costs is given for the median estimate and the 16th to 84th percentile range of the scenarios (in parentheses). The sample size of each scenario set is provided in the coloured symbols [c]. The colours of the symbols indicate the fraction of models from systematic model comparison exercises that could successfully reach the targeted concentration level. *{WGIII Table SPM.2, Table TS.2, Figure TS.13, Figure 6.24, Figure 6.25}*

	Mitigation cost increases in scenarios with limited availability of technologies [d] *[% increase in total discounted [e] mitigation costs (2015–2100) relative to default technology assumptions]*				**Mitigation cost increases due to delayed additional mitigation until 2030** *[% increase in mitigation costs relative to immediate mitigation]*	
2100 concentrations (ppm CO_2-eq)	no CCS	nuclear phase out	limited solar/wind	limited bioenergy	medium term costs (2030–2050)	long term costs (2050–2100)
450 (430 to 480)	138% (29 to 297%) 4	7% (4 to 18%) 8	6% (2 to 29%) 8	64% (44 to 78%) 8	44% (2 to 78%) 29	37% (16 to 82%) 29
500 (480 to 530)	not available (n.a.)	n.a.	n.a.	n.a.		
550 (530 to 580)	39% (18 to 78%) 11	13% (2 to 23%) 10	8% (5 to 15%) 10	18% (4 to 66%) 12	15% (3 to 32%)	16% (5 to 24%)
580 to 650	n.a.	n.a.	n.a.	n.a.		

Symbol legend—fraction of models successful in producing scenarios (numbers indicate the number of successful models)

: all models successful

: between 80 and 100% of models successful

: between 50 and 80% of models successful

: less than 50% of models successful

Notes:

[a] Delayed mitigation scenarios are associated with greenhouse gas emission of more than 55 $GtCO_2$-eq in 2030, and the increase in mitigation costs is measured relative to cost-effective mitigation scenarios for the same long-term concentration level.

[b] Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions.

[c] The range is determined by the central scenarios encompassing the 16th to 84th percentile range of the scenario set. Only scenarios with a time horizon until 2100 are included. Some models that are included in the cost ranges for concentration levels above 530 ppm CO_2-eq in 2100 could not produce associated scenarios for concentration levels below 530 ppm CO_2-eq in 2100 with assumptions about limited availability of technologies and/or delayed additional mitigation.

[d] No CCS: carbon dioxide capture and storage is not included in these scenarios. Nuclear phase out: no addition of nuclear power plants beyond those under construction, and operation of existing plants until the end of their lifetime. Limited Solar/Wind: a maximum of 20% global electricity generation from solar and wind power in any year of these scenarios. Limited Bioenergy: a maximum of 100 EJ/yr modern bioenergy supply globally (modern bioenergy used for heat, power, combinations and industry was around 18 EJ/yr in 2008). EJ = Exajoule = 10^{18} Joule.

[e] Percentage increase of net present value of consumption losses in percent of baseline consumption (for scenarios from general equilibrium models) and abatement costs in percent of baseline gross domestic product (GDP, for scenarios from partial equilibrium models) for the period 2015–2100, discounted at 5% per year.

Box 3.2 | Greenhouse Gas Metrics and Mitigation Pathways

This box focuses on emission-based metrics that are used for calculating CO_2-equivalent emissions for the formulation and evaluation of mitigation strategies. These emission metrics are distinct from the concentration-based metric used in SYR (CO_2-equivalent concentration). For an explanation of CO_2-equivalent emissions and CO_2-equivalent concentrations, see Glossary.

Emission metrics facilitate multi-component climate policies by allowing emissions of different greenhouse gases (GHGs) and other climate forcing agents to be expressed in a common unit (so-called 'CO_2-equivalent emissions'). The Global Warming Potential (GWP) was introduced in the IPCC First Assessment Report, where it was also used to illustrate the difficulties in comparing components with differing physical properties using a single metric. The 100-year GWP (GWP_{100}) was adopted by the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol and is now used widely as the default metric. It is only one of several possible emission metrics and time horizons. *{WGI 8.7, WGIII 3.9}*

The choice of emission metric and time horizon depends on type of application and policy context; hence, no single metric is optimal for all policy goals. All metrics have shortcomings, and choices contain value judgments, such as the climate effect considered and the weighting of effects over time (which explicitly or implicitly discounts impacts over time), the climate policy goal and the degree to which metrics incorporate economic or only physical considerations. There are significant uncertainties related to metrics, and the magnitudes of the uncertainties differ across metric type and time horizon. In general, the uncertainty increases for metrics along the cause–effect chain from emission to effects. *{WGI 8.7, WGIII 3.9}*

The weight assigned to non-CO_2 climate forcing agents relative to CO_2 depends strongly on the choice of metric and time horizon (*robust evidence, high agreement*). GWP compares components based on radiative forcing, integrated up to a chosen time horizon. Global Temperature change Potential (GTP; see Glossary) is based on the temperature response at a specific point in time with no weight on temperature response before or after the chosen point in time. Adoption of a fixed horizon of, for example, 20, 100 or 500 years for these metrics will inevitably put no weight on climate outcomes beyond the time horizon, which is significant for CO_2 as well as other long-lived gases. The choice of time horizon markedly affects the weighting especially of short-lived climate forcing agents, such as methane (CH_4) (see Box 3.2, Table 1; Box 3.2, Figure 1a). For some metrics (e.g., the dynamic GTP; see Glossary), the weighting changes over time as a chosen target year is approached. *{WGI 8.7, WGIII 3.9}*

Box 3.2, Table 1 | Examples of emission metric values from WGI [a].

		GWP		GTP	
	Lifetime (yr)	Cumulative forcing over 20 years	Cumulative forcing over 100 years	Temperature change after 20 years	Temperature change after 100 years
CO_2	[b]	1	1	1	1
CH_4	12.4	84	28	67	4
N_2O	121.0	264	265	277	234
CF_4	50,000.0	4880	6630	5270	8040
HFC-152a	1.5	506	138	174	19

Notes:

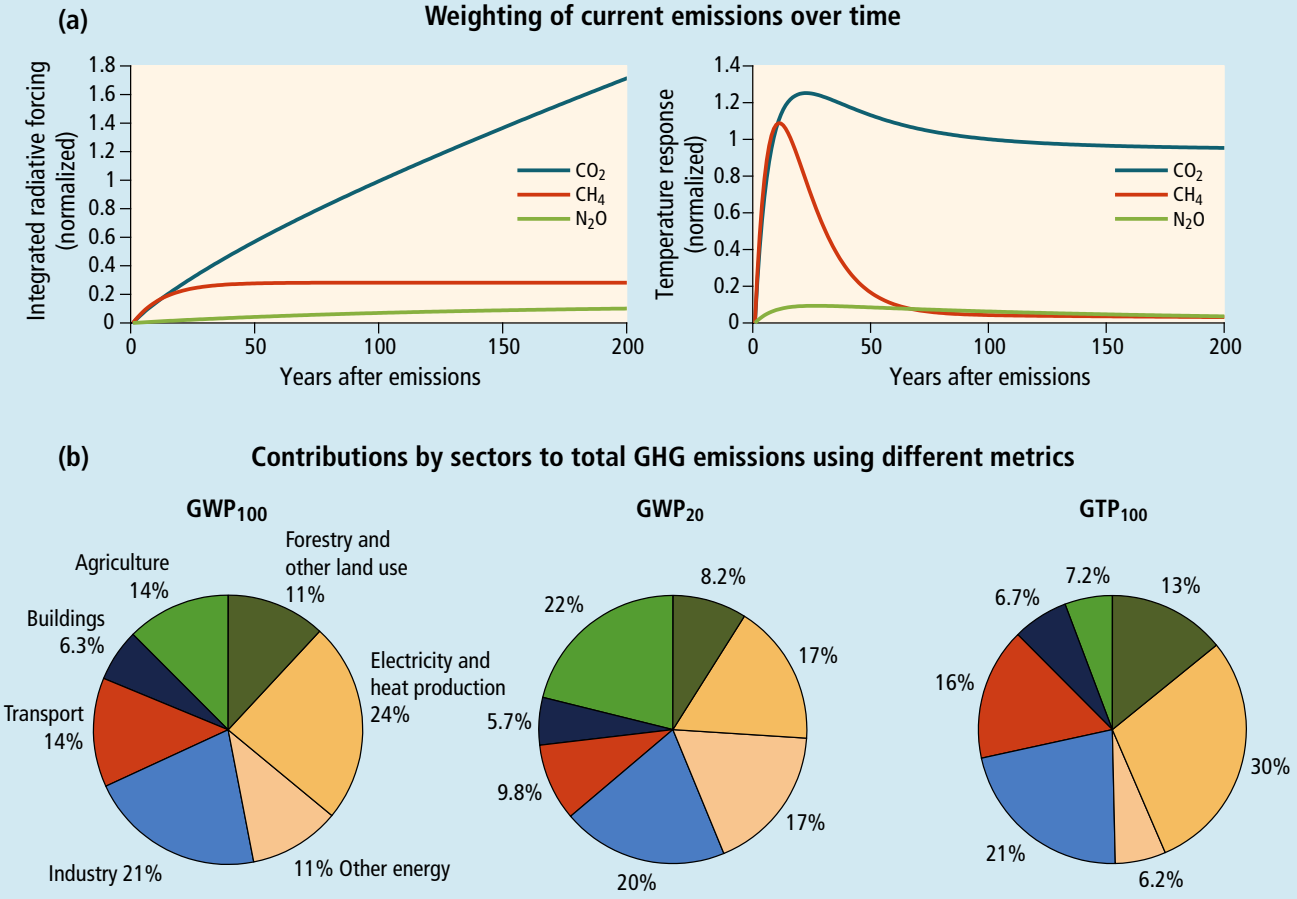
[a] Global Warming Potential (GWP) values have been updated in successive IPCC reports; the AR5 GWP_{100} values are different from those adopted for the Kyoto Protocol's First Commitment Period which are from the IPCC Second Assessment Report (SAR). Note that for consistency, equivalent CO_2 emissions given elsewhere in this Synthesis Report are also based on SAR, not AR5 values. For a comparison of emissions using SAR and AR5 GWP_{100} values for 2010 emissions, see Figure 1.6.

[b] No single lifetime can be given for CO_2. *{WGI Box 6.1, 6.1.1, 8.7}*

The choice of emission metric affects the timing and emphasis placed on abating short- and long-lived climate forcing agents. For most metrics, global cost differences are small under scenarios of global participation and cost-minimizing mitigation pathways, but implications for some individual countries and sectors could be more significant (*medium evidence, high agreement*). Different metrics and time horizons significantly affect the contributions from various sources/sectors and components, particularly short-lived climate forcing agents (Box 3.2, Figure 1b). A fixed time independent metric that gives less weight to short-lived agents such as CH_4 (e.g., using GTP_{100} instead of GWP_{100}) would require earlier and more stringent CO_2 abatement to achieve the same climate outcome for 2100. Using a time-dependent metric, such as a dynamic GTP, leads to less CH_4 mitigation

Box 3.2 (continued)

in the near term but to more in the long term as the target date is being approached. This implies that for some (short-lived) agents, the metric choice influences the choice of policies and the timing of mitigation (especially for sectors and countries with high non-CO_2 emission levels). *{WGI 8.7, WGIII 6.3}*



Box 3.2, Figure 1 | Implications of metric choices on the weighting of greenhouse gas (GHG) emissions and contributions by sectors for illustrative time horizons. Panel **(a)**: integrated radiative forcing (left panel) and warming resulting at a given future point in time (right panel) from global net emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in the year 2010 (and no emissions thereafter), for time horizons of up to 200 years. Integrated radiative forcing is used in the calculation of Global Warming Potentials (GWP), while the warming at a future point in time is used in the calculation of Global Temperature change Potentials (GTP). Radiative forcing and warming were calculated based on global 2010 emission data from WGIII 5.2 and absolute GWPs and absolute GTPs from WGI 8.7, normalized to the integrated radiative forcing and warming, respectively, after 100 years, due to 2010 net CO_2 emissions. Panel **(b)**: Illustrative examples showing contributions from different sectors to total metric-weighted global GHG emissions in the year 2010, calculated using 100-year GWP (GWP_{100}, left), 20-year GWP (GWP_{20}, middle) or 100-year GTP (GTP_{100}, right) and the WGIII 2010 emissions database. *{WGIII 5.2}* Note that percentages differ slightly for the GWP_{100} case if values from the IPCC Second Assessment Report are used; see Topic 1, Figure 1.7. See WGIII for details of activities resulting in emissions in each sector.

Box 3.3 | Carbon Dioxide Removal and Solar Radiation Management Geoengineering Technologies—Possible Roles, Options, Risks and Status

Geoengineering refers to a broad set of methods and technologies operating on a large scale that aim to deliberately alter the climate system in order to alleviate the impacts of climate change. Most methods seek to either reduce the amount of absorbed solar energy in the climate system (Solar Radiation Management, SRM) or increase the removal of carbon dioxide (CO_2) from the atmosphere by sinks to alter climate (Carbon Dioxide Removal, CDR, see Glossary). Limited evidence precludes a comprehensive assessment of feasibility, cost, side effects and environmental impacts of either CDR or SRM. *{WGI SPM E.8, 6.5, 7.7, WGII 6.4, Table 6-5, Box 20-4, WGIII TS.3.1.3, 6.9}*

CDR plays a major role in many mitigation scenarios. Bioenergy with carbon dioxide capture and storage (BECCS) and afforestation are the only CDR methods included in these scenarios. CDR technologies are particularly important in scenarios that temporarily overshoot atmospheric concentrations, but they are also prevalent in many scenarios without overshoot to compensate for residual emissions from sectors where mitigation is more expensive. Similar to mitigation, CDR would need to be deployed on a large scale and over a long time period to be able to significantly reduce CO_2 concentrations (see Section 3.1). *{WGII 6.4, WGIII SPM 4.1, TS.3.1.2, TS 3.1.3, 6.3, 6.9}*

Several CDR techniques could potentially reduce atmospheric greenhouse gas (GHG) levels. However, there are biogeochemical, technical and societal limitations that, to varying degrees, make it difficult to provide quantitative estimates of the potential for CDR. The emission mitigation from CDR is less than the removed CO_2, as some CO_2 is released from that previously stored in oceans and terrestrial carbon reservoirs. Sub-sea geologic storage has been implemented on a regional scale, with no evidence to date of ocean impact from leakage. The climatic and environmental side effects of CDR depend on technology and scale. Examples are associated with altered surface reflectance from afforestation and ocean de-oxygenation from ocean fertilization. Most terrestrial CDR techniques would involve competing demands for land and could involve local and regional risks, while maritime CDR techniques may involve significant risks for ocean ecosystems, so that their deployment could pose additional challenges for cooperation between countries. *{WGI 6.5, FAQ 7.3, WGII 6.4, Table 6.5, WGIII 6.9}*

SRM is untested, and is not included in any of the mitigation scenarios, but, if realisable, could to some degree offset global temperature rise and some of its effects. It could possibly provide rapid cooling in comparison to CO_2 mitigation. There is *medium confidence* that SRM through stratospheric aerosol injection is scalable to counter radiative forcing from a twofold increase in CO_2 concentrations and some of the climate responses associated with warming. Due to insufficient understanding there is no consensus on whether a similarly large negative counter radiative forcing could be achieved from cloud brightening. Land albedo change does not appear to be able to produce a large counter radiative forcing. Even if SRM could counter the global mean warming, differences in spatial patterns would remain. The scarcity of literature on other SRM techniques precludes their assessment. *{WGI 7.7, WGIII TS.3.1.3, 6.9}*

If it were deployed, SRM would entail numerous uncertainties, side effects, risks and shortcomings. Several lines of evidence indicate that SRM would itself produce a small but significant decrease in global precipitation (with larger differences on regional scales). Stratospheric aerosol SRM is *likely* to modestly increase ozone losses in the polar stratosphere. SRM would not prevent the CO_2 effects on ecosystems and ocean acidification that are unrelated to warming. There could also be other unanticipated consequences. For all future scenarios considered in AR5, SRM would need to increase commensurately, to counter the global mean warming, which would exacerbate side effects. Additionally, if SRM were increased to substantial levels and then terminated, there is *high confidence* that surface temperatures would rise very rapidly (within a decade or two). This would stress systems that are sensitive to the rate of warming. *{WGI 7.6–7.7, FAQ 7.3, WGII 19.5, WGIII 6.9}*

SRM technologies raise questions about costs, risks, governance and ethical implications of development and deployment. There are special challenges emerging for international institutions and mechanisms that could coordinate research and possibly restrain testing and deployment. Even if SRM would reduce human-made global temperature increase, it would imply spatial and temporal redistributions of risks. SRM thus introduces important questions of intragenerational and intergenerational justice. Research on SRM, as well as its eventual deployment, has been subject to ethical objections. In spite of the estimated low potential costs of some SRM deployment technologies, they will not necessarily pass a benefit–cost test that takes account of the range of risks and side effects. The governance implications of SRM are particularly challenging, especially as unilateral action might lead to significant effects and costs for others. *{WGIII TS.3.1.3, 1.4, 3.3, 6.9, 13.4}*

3.5 Interaction among mitigation, adaptation and sustainable development

Climate change is a threat to equitable and sustainable development. Adaptation, mitigation and sustainable development are closely related, with potential for synergies and trade-offs.

Climate change poses an increasing threat to equitable and sustainable development (*high confidence*). Some climate-related impacts on development are already being observed. Climate change is a threat multiplier. It exacerbates other threats to social and natural systems, placing additional burdens particularly on the poor and constraining possible development paths for all. Development along current global pathways can contribute to climate risk and vulnerability, further eroding the basis for sustainable development. *{WGII SPM B-2, 2.5, 10.9, 13.1–13.3, 20.1, 20.2, 20.6, WGIII SPM.2, 4.2}*

Aligning climate policy with sustainable development requires attention to both adaptation and mitigation (*high confidence*). Interaction among adaptation, mitigation and sustainable development occurs both within and across regions and scales, often in the context of multiple stressors. Some options for responding to climate change could impose risks of other environmental and social costs, have adverse distributional effects and draw resources away from other development priorities, including poverty eradication. *{WGII 2.5, 8.4, 9.3, 13.3–13.4, 20.2–20.4, 21.4, 25.9, 26.8, WGIII SPM.2, 4.8, 6.6}*

Both adaptation and mitigation can bring substantial co-benefits (*medium confidence*). Examples of actions with co-benefits include (i) improved air quality (see Figure 3.5); (ii) enhanced energy security, (iii) reduced energy and water consumption in urban areas through greening cities and recycling water; (iv) sustainable agriculture and forestry; and (v) protection of ecosystems for carbon storage and other ecosystem services. *{WGII SPM C-1, WGIII SPM.4.1}*

Strategies and actions can be pursued now that will move towards climate-resilient pathways for sustainable development, while at the same time helping to improve livelihoods, social and economic well-being and effective environmental management (*high confidence*). Prospects for climate-resilient pathways are related fundamentally to what the world accomplishes with climate change mitigation (*high confidence*). Since mitigation reduces the rate as well as the magnitude of warming, it also increases the time available for adaptation to a particular level of climate change, potentially by several decades. Delaying mitigation actions may reduce options for climate-resilient pathways in the future. *{WGII SPM C-2, 20.2, 20.6.2}*

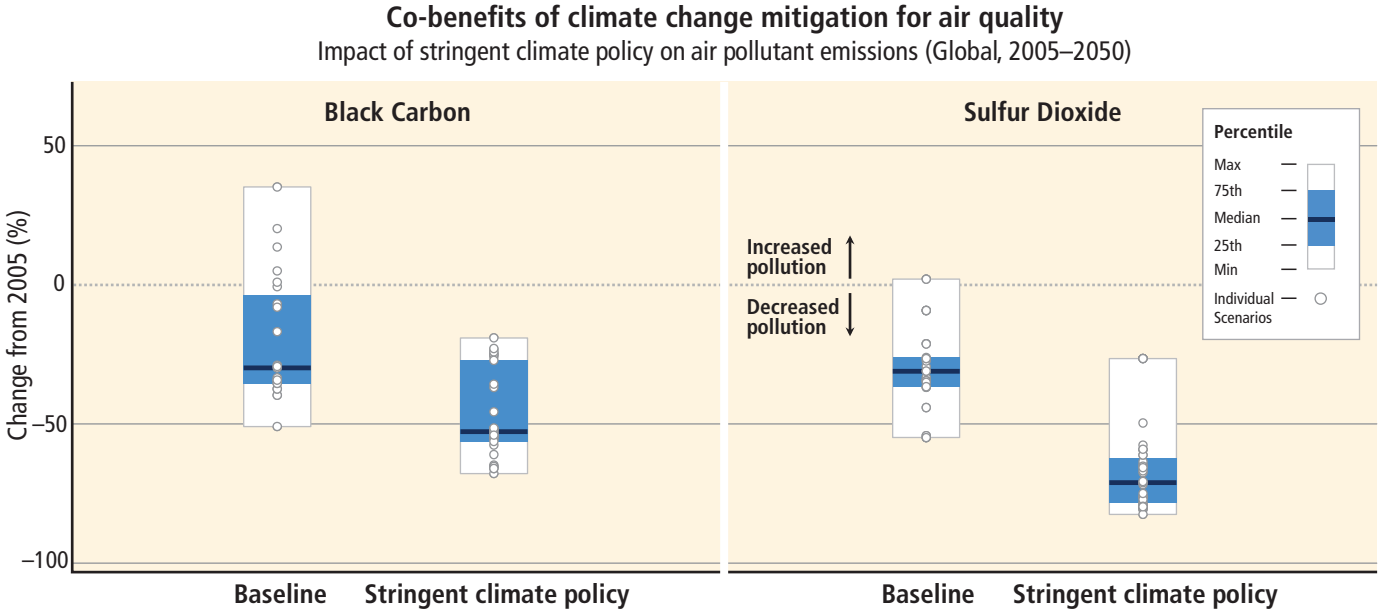


Figure 3.5 | Air pollutant emission levels of black carbon (BC) and sulfur dioxide (SO_2) by 2050, relative to 2005 (0 = 2005 levels). Baseline scenarios without additional efforts to reduce greenhouse gas (GHG) emissions beyond those in place today are compared to scenarios with stringent mitigation policies, which are consistent with reaching about 450 to about 500 (430 to 530) ppm CO_2-eq concentration levels by 2100. *{WGIII SPM.6, TS.14, Figure 6.33}*

Box 3.4 | Co-benefits and Adverse Side effects

A government policy or a measure intended to achieve one objective often affects other objectives, either positively or negatively. For example, mitigation policies can influence local air quality (see Figure 3.5). When the effects are positive they are called 'co-benefits', also referred to as 'ancillary benefits'. Negative effects are referred to as 'adverse side effects'. Some measures are labelled 'no or low regret' when their co-benefits are sufficient to justify their implementation, even in the absence of immediate direct benefits. Co-benefits and adverse side effects can be measured in monetary or non-monetary units. The effect of co-benefits and adverse side effects from climate policies on overall social welfare has not yet been quantitatively examined, with the exception of a few recent multi-objective studies. Many of these have not been well quantified, and effects can be case and site-specific as they will depend on local circumstances. *{WGII 11.9, 16.3.1, 17.2, 20.4.1, WGIII Box TS.11, 3.6, 5.7}*

Co-benefits of mitigation could affect achievement of other objectives, such as those related to energy security, air quality, efforts to address ecosystem impacts, income distribution, labour supply and employment and urban sprawl (see Table 4.2 and Table 4.5). In the absence of complementary policies, however, some mitigation measures may have adverse side effects (at least in the short term), for example on biodiversity, food security, energy access, economic growth and income distribution. The co-benefits of adaptation policies may include improved access to infrastructure and services, extended education and health systems, reduced disaster losses, better governance and others. *{WGII 4.4.4, 11.9, 15.2, 17.2, 20.3.3, 20.4.1, WGIII Box TS.11, 6.6}*

Comprehensive strategies in response to climate change that are consistent with sustainable development take into account the co-benefits, adverse side effects and risks that may arise from both adaptation and mitigation options. The assessment of overall social welfare impacts is complicated by this interaction between climate change response options and pre-existing non-climate policies. For example, in terms of air quality, the value of the extra tonne of sulfur dioxide (SO_2) reduction that occurs with climate change mitigation through reduced fossil fuel combustion depends greatly on the stringency of SO_2 control policies. If SO_2 policy is weak, the value of SO_2 reductions may be large, but if SO_2 policy is stringent, it may be near zero. Similarly, in terms of adaptation and disaster risk management, weak policies can lead to an adaptation deficit that increases human and economic losses from natural climate variability. 'Adaptation deficit' refers to the lack of capacity to manage adverse impacts of current climate variability. An existing adaptation deficit increases the benefits of adaptation policies that improve the management of climate variability and change. *{WGII 20.4.1, WGIII Box TS.11, 6.3}*

4 Adaptation and Mitigation

Topic 4: Adaptation and Mitigation

Many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales and can be enhanced through integrated responses that link mitigation and adaptation with other societal objectives.

Topic 3 demonstrates the need and strategic considerations for both adaptation and global-scale mitigation to manage risks from climate change. Building on these insights, Topic 4 presents near-term response options that could help achieve such strategic goals. Near-term adaptation and mitigation actions will differ across sectors and regions, reflecting development status, response capacities and near- and long-term aspirations with regard to both climate and non-climate outcomes. Because adaptation and mitigation inevitably take place in the context of multiple objectives, particular attention is given to the ability to develop and implement integrated approaches that can build on co-benefits and manage trade-offs.

4.1 Common enabling factors and constraints for adaptation and mitigation responses

Adaptation and mitigation responses are underpinned by common enabling factors. These include effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods and behavioural and lifestyle choices.

Innovation and investments in environmentally sound infrastructure and technologies can reduce greenhouse gas (GHG) emissions and enhance resilience to climate change (*very high confidence*). Innovation and change can expand the availability and/or effectiveness of adaptation and mitigation options. For example, investments in low-carbon and carbon-neutral energy technologies can reduce the energy intensity of economic development, the carbon intensity of energy, GHG emissions, and the long-term costs of mitigation. Similarly, new technologies and infrastructure can increase the resilience of human systems while reducing adverse impacts on natural systems. Investments in technology and infrastructure rely on an enabling policy environment, access to finance and technology and broader economic development that builds capacity (Table 4.1, Section 4.4). *{WGII SPM C-2, Table SPM.1, Table TS.8, WGIII SPM.4.1, Table SPM.2, TS.3.1.1, TS 3.1.2, TS.3.2.1}*

Adaptation and mitigation are constrained by the inertia of global and regional trends in economic development, GHG emissions, resource consumption, infrastructure and settlement patterns, institutional behaviour and technology (*medium evidence, high agreement*). Such inertia may limit the capacity to reduce GHG emissions, remain below particular climate thresholds or avoid adverse impacts (Table 4.1). Some constraints may be overcome through new technologies, financial resources, increased institutional effectiveness and governance or changes in social and cultural attitudes and behaviours. *{WGII SPM C-1, WGIII SPM.3, SPM.4.2, Table SPM.2}*

Vulnerability to climate change, GHG emissions, and the capacity for adaptation and mitigation are strongly influenced by livelihoods, lifestyles, behaviour and culture (*medium evidence, medium agreement*) (Table 4.1). Shifts toward more energy-intensive lifestyles can contribute to higher energy and resource consumption, driving greater energy production and GHG emissions and increasing mitigation costs. In contrast, emissions can be substantially lowered through changes in consumption patterns (see 4.3 for details). The social acceptability and/or effectiveness of climate policies are influenced by the extent to which they incentivize or depend on regionally appropriate changes in lifestyles or behaviours. Similarly, livelihoods that depend on climate-sensitive sectors or resources may be particularly vulnerable to climate change and climate change policies. Economic development and urbanization of landscapes exposed to climate hazards may increase the exposure of human settlements and reduce the resilience of natural systems. *{WGII SPM A-2, SPM B-2, Table SPM.1, TS A-1, TS A-2, TS C-1, TS C-2, 16.3.2.7, WGIII SPM.4.2, TS.2.2, 4.2}*

For many regions and sectors, enhanced capacities to mitigate and adapt are part of the foundation essential for managing climate change risks (*high confidence*). Such capacities are place- and context-specific and therefore there is no single approach for reducing risk that is appropriate across all settings. For example, developing nations with low income levels have the lowest financial, technological and institutional capacities to pursue low-carbon, climate-resilient development pathways. Although developed nations generally have greater relative capacity to manage the risks of climate change, such capacity does not necessarily translate into the implementation of adaptation and mitigation options. *{WGII SPM B-1, SPM B-2, TS B-1, TS B-2, 16.3.1.1, 16.3.2, 16.5, WGIII SPM.5.1, TS.4.3, TS.4.5, 4.6}*

Improving institutions as well as enhancing coordination and cooperation in governance can help overcome regional constraints associated with mitigation, adaptation and disaster risk reduction (*very high confidence*). Despite the presence of a wide array of multilateral, national and sub-national institutions focused on adaptation and mitigation, global GHG emissions continue to increase and identified adaptation needs have not been adequately addressed. The implementation of effective adaptation and mitigation options may necessitate new institutions and institutional arrangements that span multiple scales (*medium confidence*) (Table 4.1). *{WGII SPM B-2, TS C-1, 16.3.2.4, 16.8, WGIII SPM.4.2.5, SPM.5.1, SPM.5.2, TS.1, TS.3.1.3, TS.4.1, TS.4.2, TS.4.4}*

Table 4.1 | Common factors that constrain the implementation of adaptation and mitigation options

Constraining Factor	Potential Implications for Adaptation	Potential Implications for Mitigation
Adverse externalities of population growth and urbanization	Increase exposure of human populations to climate variability and change as well as demands for, and pressures on, natural resources and ecosystem services *{WGII 16.3.2.3, Box 16-3}*	Drive economic growth, energy demand and energy consumption, resulting in increases in greenhouse gas emissions *{WGIII SPM.3}*
Deficits of knowledge, education and human capital	Reduce national, institutional and individual perceptions of the risks posed by climate change as well as the costs and benefits of different adaptation options *{WGII 16.3.2.1}*	Reduce national, institutional and individual risk perception, willingness to change behavioural patterns and practices and to adopt social and technological innovations to reduce emissions *{WGIII SPM.3, SPM.5.1, 2.4.1, 3.10.1.5, 4.3.5, 9.8, 11.8.1}*
Divergences in social and cultural attitudes, values and behaviours	Reduce societal consensus regarding climate risk and therefore demand for specific adaptation policies and measures *{WGII 16.3.2.7}*	Influence emission patterns, societal perceptions of the utility of mitigation policies and technologies, and willingness to pursue sustainable behaviours and technologies *{WGIII SPM.2, 2.4.5, 2.6.6.1, 3.7.2.2, 3.9.2, 4.3.4, 5.5.1}*
Challenges in governance and institutional arrangements	Reduce the ability to coordinate adaptation policies and measures and to deliver capacity to actors to plan and implement adaptation *{WGII 16.3.2.8}*	Undermine policies, incentives and cooperation regarding the development of mitigation policies and the implementation of efficient, carbon-neutral and renewable energy technologies *{WGIII SPM.3, SPM.5.2, 4.3.2, 6.4.3, 14.1.3.1, 14.3.2.2, 15.12.2, 16.5.3}*
Lack of access to national and international climate finance	Reduces the scale of investment in adaptation policies and measures and therefore their effectiveness *{WGII 16.3.2.5}*	Reduces the capacity of developed and, particularly, developing nations to pursue policies and technologies that reduce emissions. *{WGIII TS.4.3, 12.6.2, 16.2.2.2}*
Inadequate technology	Reduces the range of available adaptation options as well as their effectiveness in reducing or avoiding risk from increasing rates or magnitudes of climate change *{WGII 16.3.2.1}*	Slows the rate at which society can reduce the carbon intensity of energy services and transition toward low-carbon and carbon-neutral technologies *{WGIII TS.3.1.3, 4.3.6, 6.3.2.2, 11.8.4}*
Insufficient quality and/or quantity of natural resources	Reduce the coping range of actors, vulnerability to non-climatic factors and potential competition for resources that enhances vulnerability *{WGII 16.3.2.3}*	Reduce the long-term sustainability of different energy technologies *{WGIII 4.3.7, 4.4.1, 11.8.3}*
Adaptation and development deficits	Increase vulnerability to current climate variability as well as future climate change *{WGII TS A-1, Table TS 5, 16.3.2.4}*	Reduce mitigative capacity and undermine international cooperative efforts on climate owing to a contentious legacy of cooperation on development *{WGIII 4.3.1, 4.6.1}*
Inequality	Places the impacts of climate change and the burden of adaptation disproportionately on the most vulnerable and/or transfers them to future generations *{WGII TS B-2, Box TS 4, Box 13-1, 16.7}*	Constrains the ability for developing nations with low income levels, or different communities or sectors within nations, to contribute to greenhouse gas mitigation *{WGIII 4.6.2.1}*

4.2 Response options for adaptation

Adaptation options exist in all sectors, but their context for implementation and potential to reduce climate-related risks differs across sectors and regions. Some adaptation responses involve significant co-benefits, synergies and trade-offs. Increasing climate change will increase challenges for many adaptation options.

People, governments and the private sector are starting to adapt to a changing climate. Since the IPCC Fourth Assessment Report (AR4), understanding of response options has increased, with improved knowledge of their benefits, costs and links to sustainable development. Adaptation can take a variety of approaches depending on its context in vulnerability reduction, disaster risk management or proactive adaptation planning. These include (see Table 4.2 for examples and details):

- Social, ecological asset and infrastructure development
- Technological process optimization
- Integrated natural resources management
- Institutional, educational and behavioural change or reinforcement
- Financial services, including risk transfer
- Information systems to support early warning and proactive planning

There is increasing recognition of the value of social (including local and indigenous), institutional, and ecosystem-based measures and of the extent of constraints to adaptation. Effective strategies and actions consider the potential for co-benefits and opportunities within wider strategic goals and development plans. *{WGII SPM A-2, SPM C-1, TS A-2, 6.4, 8.3, 9.4, 15.3}*

Opportunities to enable adaptation planning and implementation exist in all sectors and regions, with diverse potential and approaches depending on context. The need for adaptation along with associated challenges is expected to increase with climate change (*very high confidence*). Examples of key adaptation approaches for particular sectors, including constraints and limits, are summarized below. *{WGII SPM B, SPM C, 16.4, 16.6, 17.2, 19.6, 19.7, Table 16.3}*

Table 4.2 | Approaches for managing the risks of climate change through adaptation. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Examples are presented in no specific order and can be relevant to more than one category. *{WGII Table SPM.1}*

Overlapping Approaches	Category	Examples	WGII References
Vulnerability & Exposure Reduction through development, planning & practices including many low-regrets measures	Human development	Improved access to education, nutrition, health facilities, energy, safe housing & settlement structures, & social support structures; Reduced gender inequality & marginalization in other forms.	8.3, 9.3, 13.1-3, 14.2-3, 22.4
	Poverty alleviation	Improved access to & control of local resources; Land tenure; Disaster risk reduction; Social safety nets & social protection; Insurance schemes.	8.3-4, 9.3, 13.1-3
	Livelihood security	Income, asset & livelihood diversification; Improved infrastructure; Access to technology & decision-making fora; Increased decision-making power; Changed cropping, livestock & aquaculture practices; Reliance on social networks.	7.5, 9.4, 13.1-3, 22.3-4, 23.4, 26.5, 27.3, 29.6, Table SM24-7
	Disaster risk management	Early warning systems; Hazard & vulnerability mapping; Diversifying water resources; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements.	8.2-4, 11.7, 14.3, 15.4, 22.4, 24.4, 26.6, 28.4, Box 25-1, Table 3-3
	Ecosystem management	Maintaining wetlands & urban green spaces; Coastal afforestation; Watershed & reservoir management; Reduction of other stressors on ecosystems & of habitat fragmentation; Maintenance of genetic diversity; Manipulation of disturbance regimes; Community-based natural resource management.	4.3-4, 8.3, 22.4, Table 3-3, Boxes 4-3, 8-2, 15-1, 25-8, 25-9 & CC-EA
	Spatial or land-use planning	Provisioning of adequate housing, infrastructure & services; Managing development in flood prone & other high risk areas; Urban planning & upgrading programs; Land zoning laws; Easements; Protected areas.	4.4, 8.1-4, 22.4, 23.7-8, 27.3, Box 25-8
Adaptation including incremental & transformational adjustments	Structural/physical	***Engineered & built-environment options***: Sea walls & coastal protection structures; Flood levees; Water storage; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements; Floating houses; Power plant & electricity grid adjustments.	3.5-6, 5.5, 8.2-3, 10.2, 11.7, 23.3, 24.4, 25.7, 26.3, 26.8, Boxes 15-1, 25-1, 25-2 & 25-8
		Technological options: New crop & animal varieties; Indigenous, traditional & local knowledge, technologies & methods; Efficient irrigation; Water-saving technologies; Desalinisation; Conservation agriculture; Food storage & preservation facilities; Hazard & vulnerability mapping & monitoring; Early warning systems; Building insulation; Mechanical & passive cooling; Technology development, transfer & diffusion.	7.5, 8.3, 9.4, 10.3, 15.4, 22.4, 24.4, 26.3, 26.5, 27.3, 28.2, 28.4, 29.6-7, Boxes 20-5 & 25-2, Tables 3-3 & 15-1
		Ecosystem-based options: Ecological restoration; Soil conservation; Afforestation & reforestation; Mangrove conservation & replanting; Green infrastructure (e.g., shade trees, green roofs); Controlling overfishing; Fisheries co-management; Assisted species migration & dispersal; Ecological corridors; Seed banks, gene banks & other *ex situ* conservation; Community-based natural resource management.	4.4, 5.5, 6.4, 8.3, 9.4, 11.7, 15.4, 22.4, 23.6-7, 24.4, 25.6, 27.3, 28.2, 29.7, 30.6, Boxes 15-1, 22-2, 25-9, 26-2 & CC-EA
		Services: Social safety nets & social protection; Food banks & distribution of food surplus; Municipal services including water & sanitation; Vaccination programs; Essential public health services; Enhanced emergency medical services.	3.5-6, 8.3, 9.3, 11.7, 11.9, 22.4, 29.6, Box 13-2
	Institutional	***Economic options***: Financial incentives; Insurance; Catastrophe bonds; Payments for ecosystem services; Pricing water to encourage universal provision and careful use; Microfinance; Disaster contingency funds; Cash transfers; Public-private partnerships.	8.3-4, 9.4, 10.7, 11.7, 13.3, 15.4, 17.5, 22.4, 26.7, 27.6, 29.6, Box 25-7
		Laws & regulations: Land zoning laws; Building standards & practices; Easements; Water regulations & agreements; Laws to support disaster risk reduction; Laws to encourage insurance purchasing; Defined property rights & land tenure security; Protected areas; Fishing quotas; Patent pools & technology transfer.	4.4, 8.3, 9.3, 10.5, 10.7, 15.2, 15.4, 17.5, 22.4, 23.4, 23.7, 24.4, 25.4, 26.3, 27.3, 30.6, Table 25-2, Box CC-CR
		National & government policies & programs: National & regional adaptation plans including mainstreaming; Sub-national & local adaptation plans; Economic diversification; Urban upgrading programs; Municipal water management programs; Disaster planning & preparedness; Integrated water resource management; Integrated coastal zone management; Ecosystem-based management; Community-based adaptation.	2.4, 3.6, 4.4, 5.5, 6.4, 7.5, 8.3, 11.7, 15.2-5, 22.4, 23.7, 25.4, 25.8, 26.8-9, 27.3-4, 29.6, Boxes 25-1, 25-2 & 25-9, Tables 9-2 & 17-1
	Social	***Educational options***: Awareness raising & integrating into education; Gender equity in education; Extension services; Sharing indigenous, traditional & local knowledge; Participatory action research & social learning; Knowledge-sharing & learning platforms.	8.3-4, 9.4, 11.7, 12.3, 15.2-4, 22.4, 25.4, 28.4, 29.6, Tables 15-1 & 25-2
		Informational options: Hazard & vulnerability mapping; Early warning & response systems; Systematic monitoring & remote sensing; Climate services; Use of indigenous climate observations; Participatory scenario development; Integrated assessments.	2.4, 5.5, 8.3-4, 9.4, 11.7, 15.2-4, 22.4, 23.5, 24.4, 25.8, 26.6, 26.8, 27.3, 28.2, 28.5, 30.6, Table 25-2, Box 26-3
		Behavioural options: Household preparation & evacuation planning; Migration; Soil & water conservation; Storm drain clearance; Livelihood diversification; Changed cropping, livestock & aquaculture practices; Reliance on social networks.	5.5, 7.5, 9.4, 12.4, 22.3-4, 23.4, 23.7, 25.7, 26.5, 27.3, 29.6, Table SM24-7, Box 25-5
Transformation	Spheres of change	***Practical***: Social & technical innovations, behavioural shifts, or institutional & managerial changes that produce substantial shifts in outcomes.	8.3, 17.3, 20.5, Box 25-5
		Political: Political, social, cultural & ecological decisions & actions consistent with reducing vulnerability & risk & supporting adaptation, mitigation & sustainable development.	14.2-3, 20.5, 25.4, 30.7, Table 14-1
		Personal: Individual & collective assumptions, beliefs, values & worldviews influencing climate-change responses.	14.2-3, 20.5, 25.4, Table 14-1

Freshwater resources

Adaptive water management techniques, including scenario planning, learning-based approaches and flexible and low-regret solutions, can help adjust to uncertain hydrological changes due to climate change and their impacts (*limited evidence, high agreement*). Strategies include adopting integrated water management, augmenting supply, reducing the mismatch between water supply and demand, reducing non-climate stressors, strengthening institutional capacities and adopting more water-efficient technologies and water-saving strategies. *{WGII SPM B-2, Assessment Box SPM.2 Table 1, SPM B-3, 3.6, 22.3–22.4, 23.4, 23.7, 24.4, 27.2–27.3, Box 25-2}*

Terrestrial and freshwater ecosystems

Management actions can reduce but not eliminate risks of impacts to terrestrial and freshwater ecosystems due to climate change (*high confidence*). Actions include maintenance of genetic diversity, assisted species migration and dispersal, manipulation of disturbance regimes (e.g., fires, floods) and reduction of other stressors. Management options that reduce non-climatic stressors, such as habitat modification, overexploitation, pollution and invasive species, increase the inherent capacity of ecosystems and their species to adapt to a changing climate. Other options include improving early warning systems and associated response systems. Enhanced connectivity of vulnerable ecosystems may also assist autonomous adaptation. Translocation of species is controversial and is expected to become less feasible where whole ecosystems are at risk. *{WGII SPM B-2, SPM B-3, Figure SPM.5, Table TS.8, 4.4, 25.6, 26.4, Box CC-RF}*

Coastal systems and low-lying areas

Increasingly, coastal adaptation options include those based on integrated coastal zone management, local community participation, ecosystems-based approaches and disaster risk reduction, mainstreamed into relevant strategies and management plans (*high confidence*). The analysis and implementation of coastal adaptation has progressed more significantly in developed countries than in developing countries (*high confidence*). The relative costs of coastal adaptation are expected to vary strongly among and within regions and countries. *{WGII SPM B-2, SPM B-3, 5.5, 8.3, 22.3, 24.4, 26.8, Box 25-1}*

Marine systems and oceans

Marine forecasting and early warning systems as well as reducing non-climatic stressors have the potential to reduce risks for some fisheries and aquaculture industries, but options for unique ecosystems such as coral reefs are limited (*high confidence*). Fisheries and some aquaculture industries with high-technology and/or large investments have high capacities for adaptation due to greater development of environmental monitoring, modelling and resource assessments. Adaptation options include large-scale translocation of industrial fishing activities and flexible management that can react to variability and change. For smaller-scale fisheries and nations with limited adaptive capacities, building social resilience, alternative livelihoods and occupational flexibility are important strategies. Adaptation options for coral reef systems are generally limited to reducing other stressors, mainly by enhancing water quality and limiting pressures from tourism and fishing, but their efficacy will be severely reduced as thermal stress and ocean acidification increase. *{WGII SPM B-2, SPM Assessment Box SPM.2 Table 1, TS B-2, 5.5, 6.4, 7.5, 25.6.2, 29.4, 30.6-7, Box CC-MB, Box CC-CR}*

Food production system/Rural areas

Adaptation options for agriculture include technological responses, enhancing smallholder access to credit and other critical production resources, strengthening institutions at local to regional levels and improving market access through trade reform (*medium confidence*). Responses to decreased food production and quality include: developing new crop varieties adapted to changes in CO_2, temperature, and drought; enhancing the capacity for climate risk management; and offsetting economic impacts of land use change. Improving financial support and investing in the production of small-scale farms can also provide benefits. Expanding agricultural markets and improving the predictability and reliability of the world trading system could result in reduced market volatility and help manage food supply shortages caused by climate change. *{WGII SPM B-2, SPM B-3, 7.5, 9.3, 22.4, 22.6, 25.9, 27.3}*

Urban areas/Key economic sectors and services

Urban adaptation benefits from effective multi-level governance, alignment of policies and incentives, strengthened local government and community adaptation capacity, synergies with the private sector and appropriate financing and institutional development (*medium confidence*). Enhancing the capacity of low-income groups and vulnerable communities and their partnerships with local governments can also be an effective urban climate adaptation strategy. Examples of adaptation mechanisms include large-scale public-private risk reduction initiatives and economic diversification and government insurance for the non-diversifiable portion of risk. In some locations, especially at the upper end of projected climate changes, responses could also require transformational changes such as managed retreat. *{WGII SPM B-2, 8.3–8.4, 24.4, 24.5, 26.8, Box 25-9}*

Human health, security and livelihoods

Adaptation options that focus on strengthening existing delivery systems and institutions, as well as insurance and social protection strategies, can improve health, security and livelihoods in the near term (*high confidence*). The most effective vulnerability reduction measures for health in the near term are programmes that implement and improve basic public health measures such as provision of clean water and sanitation, secure essential health care including vaccination and child health services, increase capacity for disaster preparedness and response and alleviate poverty (*very high confidence*). Options to address heat related mortality include health warning systems linked to response strategies, urban planning and improvements to the built environment to reduce heat stress. Robust institutions can manage many transboundary impacts of climate change to reduce risk of conflicts over shared natural resources. Insurance programmes, social protection measures and disaster risk management may enhance long-term livelihood resilience among the poor and marginalized people, if policies address multi-dimensional poverty. *{WGII SPM B-2, SPM B-3, 8.2, 10.8, 11.7–11.8, 12.5–12.6, 22.3, 23.9, 25.8, 26.6, Box CC-HS}*

Table 4.3 | Examples of potential trade-offs associated with an illustrative set of adaptation options that could be implemented by actors to achieve specific management objectives. *{WGII Table 16-2}*

Sector	Actor's adaptation objective	Adaptation option	Real or perceived trade-off
Agriculture	Enhance drought and pest resistance; enhance yields	Biotechnology and genetically modified crops	Perceived risk to public health and safety; ecological risks associated with introduction of new genetic variants to natural environments
	Provide financial safety net for farmers to ensure continuation of farming enterprises	Subsidized drought assistance; crop insurance	Creates moral hazard and distributional inequalities if not appropriately administered
	Maintain or enhance crop yields; suppress opportunistic agricultural pests and invasive species	Increased use of chemical fertilizer and pesticides	Increased discharge of nutrients and chemical pollution to the environment; adverse impacts of pesticide use on non-target species; increased emissions of greenhouse gases; increased human exposure to pollutants
Biodiversity	Enhance capacity for natural adaptation and migration to changing climatic conditions	Migration corridors; expansion of conservation areas	Unknown efficacy; concerns over property rights regarding land acquisition; governance challenges
	Enhance regulatory protections for species potentially at risk due to climate and non-climatic changes	Protection of critical habitat for vulnerable species	Addresses secondary rather than primary pressures on species; concerns over property rights; regulatory barriers to regional economic development
	Facilitate conservation of valued species by shifting populations to alternative areas as the climate changes	Assisted migration	Difficult to predict ultimate success of assisted migration; possible adverse impacts on indigenous flora and fauna from introduction of species into new ecological regions
Coasts	Provide near-term protection to financial assets from inundation and/or erosion	Sea walls	High direct and opportunity costs; equity concerns; ecological impacts to coastal wetlands
	Allow natural coastal and ecological processes to proceed; reduce long-term risk to property and assets	Managed retreat	Undermines private property rights; significant governance challenges associated with implementation
	Preserve public health and safety; minimize property damage and risk of stranded assets	Migration out of low-lying areas	Loss of sense of place and cultural identity; erosion of kinship and familial ties; impacts to receiving communities
Water resources management	Increase water resource reliability and drought resilience	Desalination	Ecological risk of saline discharge; high energy demand and associated carbon emissions; creates disincentives for conservation
	Maximize efficiency of water management and use; increase flexibility	Water trading	Undermines public good/social aspects of water
	Enhance efficiency of available water resources	Water recycling/reuse	Perceived risk to public health and safety

Significant co-benefits, synergies and trade-offs exist between adaptation and mitigation and among different adaptation responses; interactions occur both within and across regions and sectors (*very high confidence*). For example, investments in crop varieties adapted to climate change can increase the capacity to cope with drought, and public health measures to address vector-borne diseases can enhance the capacity of health systems to address other challenges. Similarly, locating infrastructure away from low-lying coastal areas helps settlements and ecosystems adapt to sea level rise while also protecting against tsunamis. However, some adaptation options may have adverse side effects that imply real or perceived trade-offs with other adaptation objectives (see Table 4.3 for examples), mitigation objectives or broader development goals. For example, while protection of ecosystems can assist adaptation to climate change and enhance carbon storage, increased use of air conditioning to maintain thermal comfort in buildings or the use of desalination to enhance water resource security can increase energy demand, and therefore, GHG emissions. *{WGII SPM B-2, SPM C-1, 5.4.2, 16.3.2.9, 17.2.3.1, Table 16-2}*

4.3 Response options for mitigation

Mitigation options are available in every major sector. Mitigation can be more cost-effective if using an integrated approach that combines measures to reduce energy use and the greenhouse gas intensity of end-use sectors, decarbonize energy supply, reduce net emissions and enhance carbon sinks in land-based sectors.

A broad range of sectoral mitigation options is available that can reduce GHG emission intensity, improve energy intensity through enhancements of technology, behaviour, production and resource efficiency and enable structural changes or changes in activity. In addition, direct options in agriculture, forestry and other land use (AFOLU) involve reducing CO_2 emissions by reducing deforestation, forest degradation and forest fires; storing carbon in terrestrial systems (for example, through afforestation); and providing bioenergy feedstocks. Options to reduce non-CO_2 emissions exist across all sectors but most notably in agriculture, energy supply and

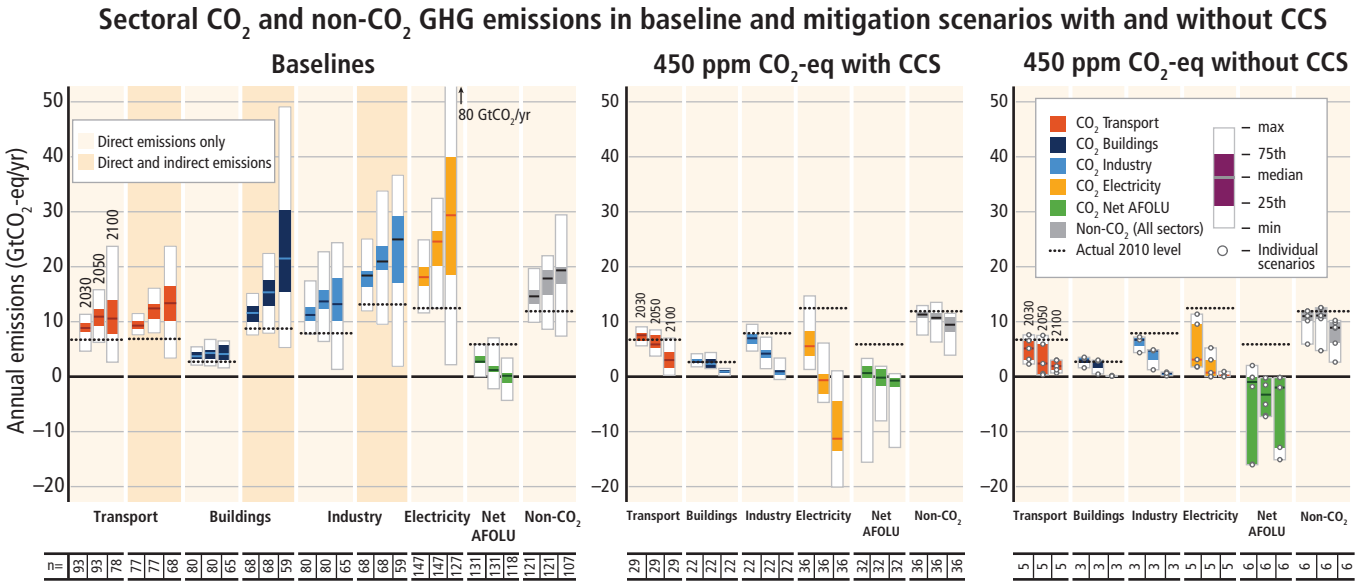


Figure 4.1 | Carbon dioxide (CO_2) emissions by sector and total non-CO_2 greenhouse gas (GHG) emissions (Kyoto gases) across sectors in baseline (left panel) and mitigation scenarios that reach about 450 (430 to 480) ppm CO_2-eq (*likely* to limit warming to 2°C above pre-industrial levels) with carbon dioxide capture and storage (CCS, middle panel) and without CCS (right panel). Light yellow background denotes direct CO_2 and non-CO_2 GHG emissions for both the baseline and mitigation scenarios. In addition, for the baseline scenarios, the sum of direct and indirect emissions from the energy end-use sectors (transport, buildings and industry) is also shown (dark yellow background). Mitigation scenarios show direct emissions only. However, mitigation in the end-use sectors leads also to indirect emissions reductions in the upstream energy supply sector. Direct emissions of the end-use sectors thus do not include the emission reduction potential at the supply-side due to, for example, reduced electricity demand. Note that for calculating the indirect emissions only electricity emissions are allocated from energy supply to end-use sectors. The numbers at the bottom of the graphs refer to the number of scenarios included in the range, which differs across sectors and time due to different sectoral resolution and time horizon of models. Note that many models cannot reach concentrations of about 450 ppm CO_2-eq by 2100 in the absence of CCS, resulting in a low number of scenarios for the right panel. Negative emissions in the electricity sector are due to the application of bioenergy with carbon dioxide capture and storage (BECCS). 'Net' agriculture, forestry and other land use (AFOLU) emissions consider afforestation, reforestation as well as deforestation activities. *{WGIII Figure SPM.7, Figure TS.15}*

industry. An overview of sectoral mitigation options and potentials is provided in Table 4.4. *{WGIII TS 3.2.1}*

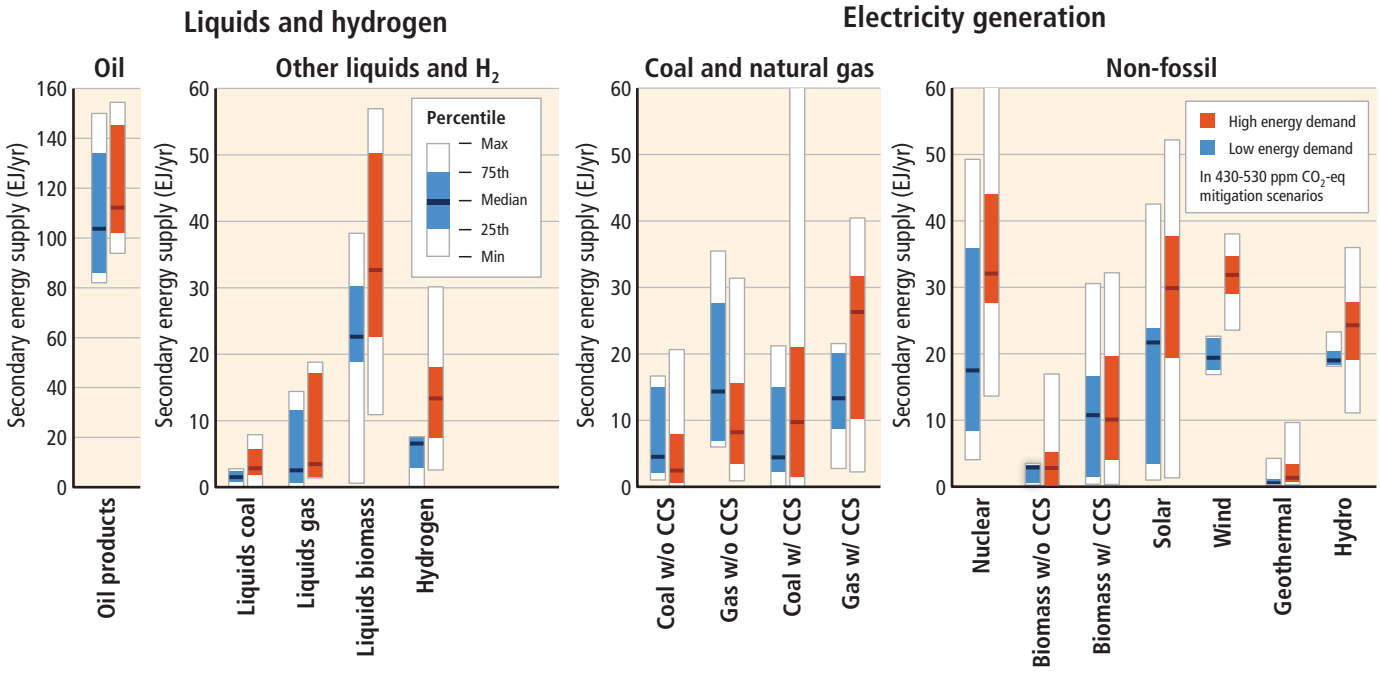
Well-designed systemic and cross-sectoral mitigation strategies are more cost-effective in cutting emissions than a focus on individual technologies and sectors with efforts in one sector affecting the need for mitigation in others (*medium confidence*). In baseline scenarios without new mitigation policies, GHG emissions are projected to grow in all sectors, except for net CO_2 emissions in the AFOLU sector (Figure 4.1, left panel). Mitigation scenarios reaching around 450 ppm CO_2-eq[42] concentration by 2100[43] (*likely* to limit warming to 2°C above pre-industrial levels) show large-scale global changes in the energy supply sector (Figure 4.1, middle and right panel). While rapid decarbonization of energy supply generally entails more flexibility for end-use and AFOLU sectors, stronger demand reductions lessen the mitigation challenge for the supply side of the energy system (Figures 4.1 and 4.2). There are thus strong interdependencies across sectors and the resulting distribution of the mitigation effort is strongly influenced by the availability and performance of future technologies, particularly BECCS and large scale afforestation (Figure 4.1, middle and right panel). The next two decades present a window of opportunity for mitigation in urban areas, as a large portion of the world's urban areas will be developed during this period. *{WGIII SPM.4.2, TS.3.2}*

Decarbonizing (i.e., reducing the carbon intensity of) electricity generation is a key component of cost-effective mitigation strategies in achieving low stabilization levels (of about 450 to about 500 ppm CO_2-eq, at least *about as likely as not* to limit warming to 2°C above pre-industrial levels) (*medium evidence, high agreement*). In most integrated modelling scenarios, decarbonization happens more rapidly in electricity generation than in the industry, buildings and transport sectors. In scenarios reaching 450 ppm CO_2-eq concentrations by 2100, global CO_2 emissions from the energy supply sector are projected to decline over the next decade and are characterized by reductions of 90% or more below 2010 levels between 2040 and 2070. *{WGIII SPM.4.2, 6.8, 7.11}*

Efficiency enhancements and behavioural changes, in order to reduce energy demand compared to baseline scenarios without compromising development, are a key mitigation strategy in scenarios reaching atmospheric CO_2-eq concentrations of about 450 to about 500 ppm by 2100 (*robust evidence, high agreement*). Near-term reductions in energy demand are an important

[42] See Glossary for definition of CO_2-eq concentrations and emissions; also Box 3.2 for metrics to calculate the CO_2-equivalence of non-CO_2 emissions and their influence on sectoral abatement strategies.

[43] For comparison, the CO_2-eq concentration in 2011 is estimated to be 430 [340 to 520] ppm.



1	2	3	4
High energy demand scenarios show higher levels of oil supply.	In high energy demand scenarios, alternative liquid and hydrogen technologies are scaled up more rapidly.	High energy demand scenarios show a more rapid up-scaling of CCS technologies but a more rapid phase-out of unabated fossil fuel conversion technologies.	In high energy demand scenarios non-fossil electricity generation technologies are scaled up more rapidly.

Figure 4.2 | Influence of energy demand on the deployment of energy supply technologies in 2050 in mitigation scenarios reaching about 450 to about 500 ppm CO_2-eq concentrations by 2100 (at least *about as likely as not* to limit warming to 2°C above pre-industrial levels). Blue bars for 'low energy demand' show the deployment range of scenarios with limited growth in final energy demand of <20% in 2050 compared to 2010. Red bars show the deployment range of technologies in a case of 'high energy demand' (>20% growth in 2050 compared to 2010). For each technology, the median, interquartile and full deployment range is displayed. Notes: Scenarios assuming technology restrictions are excluded. Ranges include results from many different integrated models. Multiple scenario results from the same model were averaged to avoid sampling biases. *{WGIII Figure TS.16}*

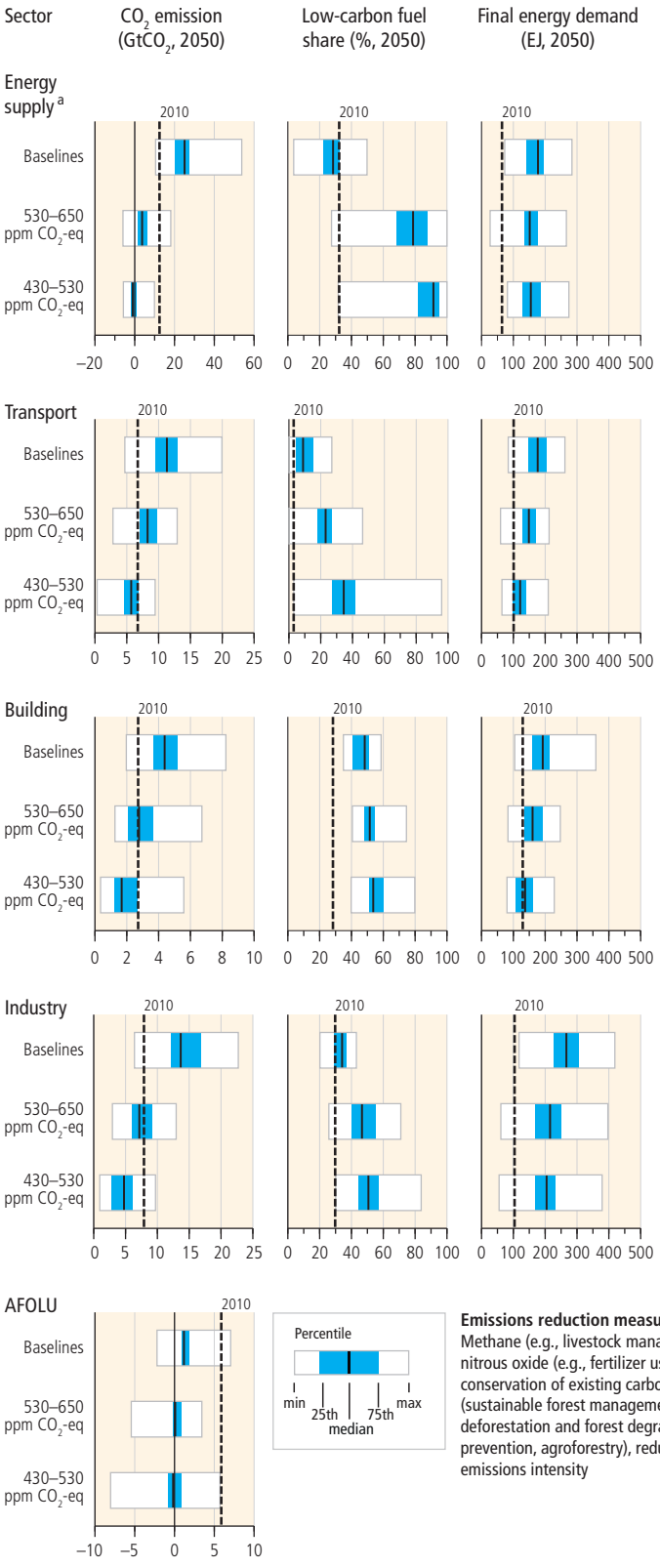
element of cost-effective mitigation strategies, provide more flexibility for reducing carbon intensity in the energy supply sector, hedge against related supply-side risks, avoid lock-in to carbon-intensive infrastructures and are associated with important co-benefits (Figure 4.2, Table 4.4). Emissions can be substantially lowered through changes in consumption patterns (e.g., mobility demand and mode, energy use in households, choice of longer-lasting products) and dietary change and reduction in food wastes. A number of options including monetary and non-monetary incentives as well as information measures may facilitate behavioural changes. *{WGIII SPM.4.2}*

Decarbonization of the energy supply sector (i.e., reducing the carbon intensity) requires upscaling of low- and zero-carbon electricity generation technologies (*high confidence*). In the majority of low-concentration stabilization scenarios (about 450 to about 500 ppm CO_2-eq , at least *about as likely as not* to limit warming to 2°C above pre-industrial levels), the share of low-carbon electricity supply (comprising renewable energy (RE), nuclear and CCS, including BECCS) increases from the current share of approximately 30% to more than 80% by 2050 and 90% by 2100, and fossil fuel power generation without CCS is phased out almost entirely by 2100. Among these low-carbon technologies, a growing number of RE technologies have achieved a level of maturity to enable deployment at significant scale since AR4 (*robust evidence, high agreement*) and nuclear energy is a mature low-GHG emission source of baseload power, but its share of global electricity generation has been declining (since 1993). GHG emissions from energy supply can be reduced significantly by replacing current world average coal-fired power plants with modern, highly efficient natural gas combined-cycle power plants or combined heat and power plants, provided that natural gas is available and the fugitive emissions associated with extraction and supply are low or mitigated. *{WGIII SPM.4.2}*

Behaviour, lifestyle and culture have a considerable influence on energy use and associated emissions, with high mitigation potential in some sectors, in particular when complementing technological and structural change (*medium evidence, medium agreement*). In the transport sector, technical and behavioural mitigation measures for all modes, plus new infrastructure and urban redevelopment investments, could reduce final energy demand significantly below baseline levels (*robust evidence, medium agreement*) (Table 4.4). While opportunities for switching to low-carbon fuels exist, the rate of decarbonization in the transport sector might be constrained by challenges associated with energy storage and the relatively low

Table 4.4 | Sectoral carbon dioxide (CO_2) emissions, associated energy system changes and examples of mitigation measures (including for non-CO_2 gases; see Box 3.2 for metrics regarding the weighting and abatement of non-CO_2 emissions). *{WGIII SPM.7, Figure SPM.8, Table TS.2, 7.11.3, 7.13, 7.14}*

Sectoral CO_2 emissions and related energy system changes



Examples for sectoral mitigation measures

Key low-carbon energy options	Key energy saving options	Other options
Renewables (wind, solar bioenergy, geothermal, hydro, etc.), nuclear, CCS, BECCS, fossil fuel switching	Energy efficiency improvements of energy supply technologies, improved transmission and distribution, CHP and cogeneration	Fugitive CH_4 emissions control
Fuel switching to low-carbon fuels (e.g., hydrogen/electricity from low-carbon sources), biofuels	Efficiency improvements (engines, vehicle design, appliances, lighter materials), modal shift (e.g., from LDVs to public transport or from aviation to HDVs to rail), eco-driving, improved freight logistics, journey avoidance, higher occupancy rates	Transport (infrastructure) planning, urban planning
Building integrated RES, fuel switching to low-carbon fuels (e.g., electricity from low-carbon sources, biofuels)	Device efficiency (heating/cooling systems, water heating, cooking, lighting, appliances), systemic efficiency (integrated design, low/zero energy buildings, district heating/cooling, CHP, smart meters/grids), behavioural and lifestyle changes (e.g., appliance use, thermostat setting, dwelling size)	Urban planning, building lifetime, durability of building components and appliances, low energy/GHG intensive construction and materials
Process emissions reductions, use of waste and CCS in industry, fuel switching among fossil fuels and switch to low-carbon energy (e.g., electricity) or biomass	Energy efficiency and BAT (e.g., furnace/boilers, steam systems, electric motors and control systems, (waste) heat exchanges, recycling), reduction of demand for goods, more intensive use of goods (e.g., improve durability or car sharing)	HFC replacement and leak repair, material efficiency (e.g., process innovation, re-using old materials, product design, etc.)

Emissions reduction measures: Methane (e.g., livestock management), nitrous oxide (e.g., fertilizer use), conservation of existing carbon pools (sustainable forest management, reduced deforestation and forest degradation, fire prevention, agroforestry), reduction in emissions intensity

Sequestration options: Increasing existing carbon pools (e.g., afforestation, reforestation, integrated systems, carbon sequestration in soils)

Substitution options: Use of biological products instead of fossil/GHG intensive products (e.g., bioenergy, insulation products)

Demand-side measures: Reduction of loss and waste of food, changes in human diets, use of long-lived wood products

[a] CO_2 emissions, low carbon fuel shares, and final energy demand are shown for electricity generation only

energy density of low-carbon transport fuels (*medium confidence*). In the building sector, recent advances in technologies, know-how and policies provide opportunities to stabilize or reduce global energy use to about current levels by mid-century. In addition, recent improvements in performance and costs make very low energy construction and retrofits of buildings economically attractive, sometimes even at net negative costs (*robust evidence, high agreement*). In the industry sector, improvements in GHG emission efficiency and in the efficiency of material use, recycling and reuse of materials and products, and overall reductions in product demand (e.g., through a more intensive use of products) and service demand could, in addition to energy efficiency, help reduce GHG emissions below the baseline level. Prevalent approaches for promoting energy efficiency in industry include information programmes followed by economic instruments, regulatory approaches and voluntary actions. Important options for mitigation in waste management are waste reduction, followed by re-use, recycling and energy recovery (*robust evidence, high agreement*). *{WGIII SPM.4.2, Box TS.12, TS.3.2}*

The most cost-effective mitigation options in forestry are afforestation, sustainable forest management and reducing deforestation, with large differences in their relative importance across regions. In agriculture, the most cost-effective mitigation options are cropland management, grazing land management and restoration of organic soils (*medium evidence, high agreement*). About a third of mitigation potential in forestry can be achieved at a cost <20 USD/tCO_2-eq emission. Demand-side measures, such as changes in diet and reductions of losses in the food supply chain, have a significant, but uncertain, potential to reduce GHG emissions from food production (*medium evidence, medium agreement*). *{WGIII SPM 4.2.4}*

Bioenergy can play a critical role for mitigation, but there are issues to consider, such as the sustainability of practices and the efficiency of bioenergy systems (*robust evidence, medium agreement*). Evidence suggests that bioenergy options with low life-cycle emissions, some already available, can reduce GHG emissions; outcomes are site-specific and rely on efficient integrated 'biomass-to-bioenergy systems', and sustainable land use management and governance. Barriers to large-scale deployment of bioenergy include concerns about GHG emissions from land, food security, water resources, biodiversity conservation and livelihoods. *{WGIII SPM.4.2}*

Mitigation measures intersect with other societal goals, creating the possibility of co-benefits or adverse side-effects. These intersections, if well-managed, can strengthen the basis for undertaking climate mitigation actions (*robust evidence, medium agreement*). Mitigation can positively or negatively influence the achievement of other societal goals, such as those related to human health, food security, biodiversity, local environmental quality, energy access, livelihoods and equitable sustainable development (see also Section 4.5). On the other hand, policies towards other societal goals can influence the achievement of mitigation and adaptation objectives. These influences can be substantial, although sometimes difficult to quantify, especially in welfare terms. This multi-objective perspective is important in part because it helps to identify areas where support for policies that advance multiple goals will be robust. Potential co-benefits and adverse side effects of the main sectoral mitigation measures are summarized in Table 4.5. Overall, the potential for co-benefits for energy end-use measures outweigh the potential for adverse side effects, whereas the evidence suggests this may not be the case for all energy supply and AFOLU measures. *{WGIII SPM.2}*

4.4 Policy approaches for adaptation and mitigation, technology and finance

Effective adaptation and mitigation responses will depend on policies and measures across multiple scales: international, regional, national and sub-national. Policies across all scales supporting technology development, diffusion and transfer, as well as finance for responses to climate change, can complement and enhance the effectiveness of policies that directly promote adaptation and mitigation.

4.4.1 International and regional cooperation on adaptation and mitigation

Because climate change has the characteristics of a collective action problem at the global scale (see 3.1), effective mitigation will not be achieved if individual agents advance their own interests independently, even though mitigation can also have local co-benefits. Cooperative responses, including international cooperation, are therefore required to effectively mitigate GHG emissions and address other climate change issues. While adaptation focuses primarily on local to national scale outcomes, its effectiveness can be enhanced through coordination across governance scales, including international cooperation. In fact, international cooperation has helped to facilitate the creation of adaptation strategies, plans, and actions at national, sub-national, and local levels. A variety of climate policy instruments have been employed, and even more could be employed, at international and regional levels to address mitigation and to support and promote adaptation at national and sub-national scales. Evidence suggests that outcomes seen as equitable can lead to more effective cooperation. *{WGII SPM C-1, 2.2, 15.2, WGIII 13.ES, 14.3, 15.8, SREX SPM, 7.ES}*

The United Nations Framework Convention on Climate Change (UNFCCC) is the main multilateral forum focused on addressing climate change, with nearly universal participation. UNFCCC activities since 2007, which include the 2010 Cancún Agreements and the 2011 Durban Platform for Enhanced Action, have sought to enhance actions under the Convention, and have led to an increasing number of institutions and other arrangements for international climate change cooperation. Other institutions organized at different levels of governance have resulted in diversifying international climate change cooperation. *{WGIII SPM.5.2, 13.5}*

Existing and proposed international climate change cooperation arrangements vary in their focus and degree of centralization and coordination. They span: multilateral agreements, harmonized national policies and decentralized but coordinated national policies, as well as regional and regionally-coordinated policies (see Figure 4.3). *{WGIII SPM.5.2}*

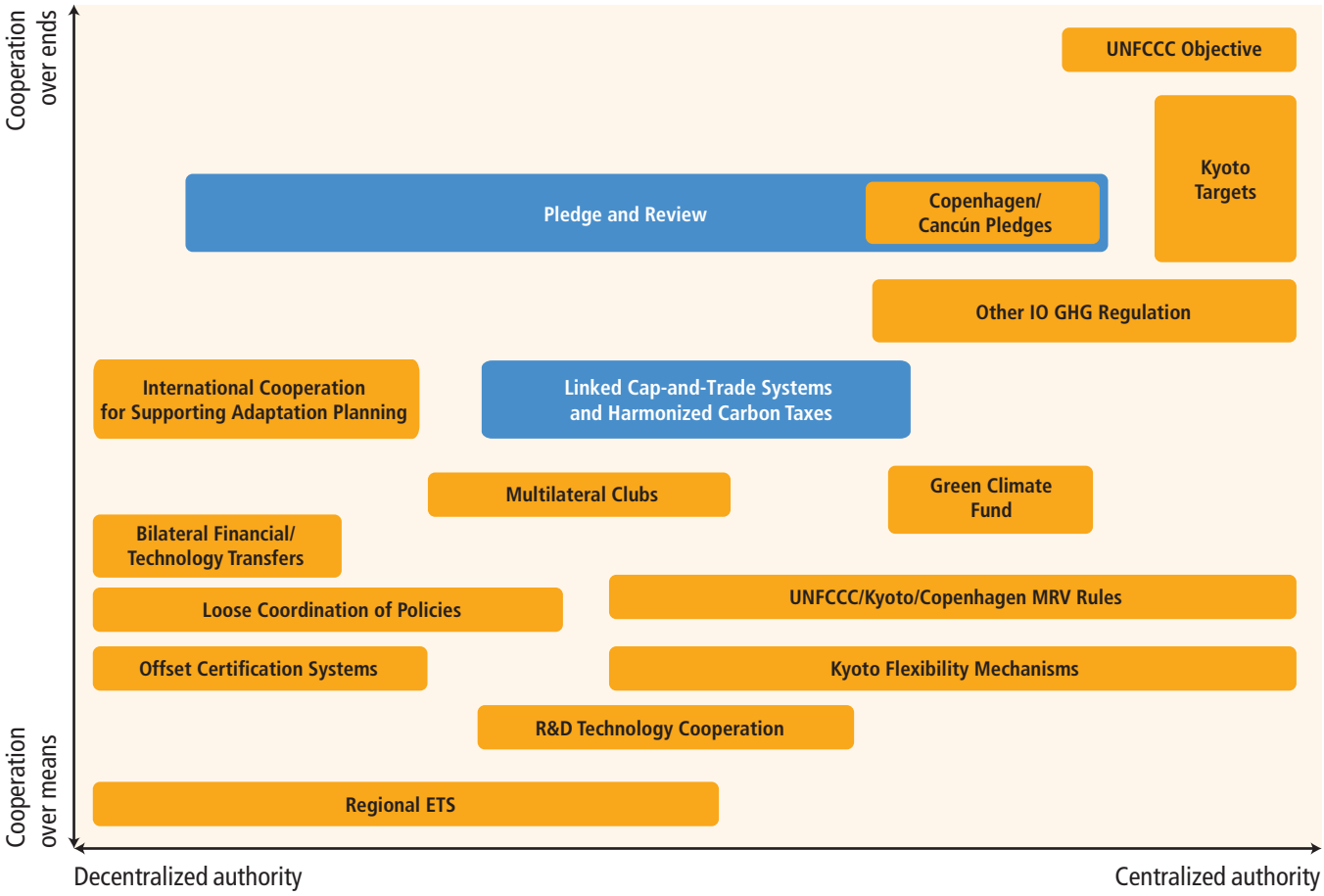
Table 4.5 | Potential co-benefits (blue text) and adverse side effects (red text) of the main sectoral mitigation measures. Co-benefits and adverse side effects, and their overall positive or negative effect, all depend on local circumstances as well as on the implementation practice, pace and scale. For an assessment of macroeconomic, cross-sectoral effects associated with mitigation policies, see Section 3.4. The uncertainty qualifiers between brackets denote the level of evidence and agreement on the respective effect. Abbreviations for evidence: l = limited, m = medium, r = robust; for agreement: l = low, m = medium, h = high. *{WGIII Table TS.3, Table TS.4, Table TS.5, Table TS.6, Table TS.7, Table 6.7}*

Sectoral mitigation measures	Effect on additional objectives/concerns		
	Economic	**Social**	**Environmental**
Energy Supply	*For possible upstream effects of biomass supply for bioenergy, see AFOLU.*		
Nuclear replacing coal power	Energy security (reduced exposure to fuel price volatility) (***m/m***); local employment impact (but uncertain net effect) (***l/m***); legacy/cost of waste and abandoned reactors (***m/h***)	Mixed health impact via reduced air pollution and coal mining accidents (***m/h***), nuclear accidents and waste treatment, uranium mining and milling (***m/l***); safety and waste concerns (***r/h***); proliferation risk (***m/m***)	Mixed ecosystem impact via reduced air pollution (***m/h***) and coal mining (***l/h***), nuclear accidents (***m/m***)
Renewable energy (wind, PV, CSP, hydro, geothermal, bioenergy) replacing coal	Energy security (***r/m***); local employment (but uncertain net effect) (***m/m***); water management (for some hydro energy) (***m/h***); extra measures to match demand (for PV, wind, some CSP) (***r/h***); higher use of critical metals for PV and direct drive wind turbines (***r/m***)	Reduced health impact via reduced air pollution (except bioenergy) (***r/h***) and coal mining accidents (***m/h***); contribution to (off-grid) energy access (***m/l***); threat of displacement (for large hydro installations) (***m/h***)	Mixed ecosystem impact via reduced air pollution (except bioenergy) (***m/h***) and coal mining (***l/h***), habitat impact (for some hydro energy) (***m/m***), landscape and wildlife impact (***m/m***); lower/higher water use (for wind, PV (***m/m***); bioenergy, CSP, geothermal and reservoir hydro (***m/h***))
Fossil energy with CCS replacing coal	Preservation vs. lock-in of human and physical capital in the fossil industry (***m/m***); long-term monitoring of CO_2 storage (***m/h***)	Health impact via risk of CO_2 leakage (***m/m***) and additional upstream supply-chain activities (***m/h***); safety concerns (CO_2 storage and transport) (***m/h***)	Ecosystem impact via additional upstream supply-chain activities (***m/m***) and higher water use (***m/h***)
CH_4 leakage prevention, capture or treatment	Energy security (potential to use gas in some cases) (***l/h***)	Reduced health impact via reduced air pollution (***m/m***); occupational safety at coal mines (***m/m***)	Reduced ecosystem impact via reduced air pollution (***l/m***)
Transport	*For possible upstream effects of low-carbon electricity, see Energy Supply. For biomass supply, see AFOLU.*		
Reduction of carbon intensity of fuel	Energy security (diversification, reduced oil dependence and exposure to oil price volatility) (***m/m***); technological spillovers (***l/l***)	Mixed health impact via increased/reduced urban air pollution by electricity and hydrogen (***r/h***), diesel (***l/m***); road safety concerns (***l/l***) but reduced health impact via reduced noise (***l/m***) of electric LDVs	Mixed ecosystem impact of electricity and hydrogen via reduced urban air pollution (***m/m***) and material use (unsustainable mining) (***l/l***)
Reduction of energy intensity	Energy security (reduced oil dependence and exposure to oil price volatility) (***m/m***)	Reduced health impact via reduced urban air pollution (***r/h***); road safety (crash-worthiness depending on the design of the standards) (***m/m***)	Reduced ecosystem and biodiversity impact via reduced urban air pollution (***m/h***)
Compact urban form and improved transport infrastructure Modal shift	Energy security (reduced oil dependence and exposure to oil price volatility) (***m/m***); productivity (reduced urban congestion and travel times, affordable and accessible transport) (***m/h***)	Mixed health impact for non-motorized modes via increased physical activity (***r/h***), potentially higher exposure to air pollution (***r/h***), reduced noise (via modal shift and travel reduction) (***r/h***); equitable mobility access to employment opportunities (***r/h***); road safety (via modal shift) (***r/h***)	Reduced ecosystem impact via reduced urban air pollution (***r/h***) and land use competition (***m/m***)
Journey distance reduction and avoidance	Energy security (reduced oil dependence and exposure to oil price volatility) (***r/h***); productivity (reduced urban congestion/travel times, walking) (***r/h***)	Reduced health impact (for non-motorized transport modes) (***r/h***)	Mixed ecosystem impact via reduced urban air pollution (***r/h***), new/shorter shipping routes (***r/h***); reduced land use competition from transport infrastructure (***r/h***)
Buildings	*For possible upstream effects of fuel switching and RES, see Energy Supply.*		
Reduction of GHG emissions intensity (e.g., fuel switching, RES incorporation, green roofs)	Energy security (***m/h***); employment impact (***m/m***); lower need for energy subsidies (***l/l***); asset values of buildings (***l/m***)	Fuel poverty alleviation via reduced energy demand (***m/h***); energy access (for higher energy cost) (***l/m***); productive time for women/children (for replaced traditional cookstoves) (***m/h***)	Reduced health impact in residential buildings and ecosystem impact (via reduced fuel poverty (***r/h***), indoor/outdoor air pollution (***r/h***) and UHI effect) (***l/m***); urban biodiversity (for green roofs) (***m/m***)
Retrofits of existing buildings Exemplary new buildings Efficient equipment	Energy security (***m/h***); employment impact (***m/m***); productivity (for commercial buildings) (***m/h***); less need for energy subsidies (***l/l***); asset value of buildings (***l/m***); disaster resilience (***l/m***)	Fuel poverty alleviation via reduced energy demand (for retrofits and efficient equipment) (***m/h***); energy access (higher housing cost) (***l/m***); thermal comfort (***m/h***); productive time for women and children (for replaced traditional cookstoves) (***m/h***)	Reduced health and ecosystem impact (e.g., via reduced fuel poverty (***r/h***), indoor/outdoor air pollution (***r/h***), UHI effect (***l/m***), improved indoor environmental conditions (***m/h***)); health risk via insufficient ventilation (***m/m***); reduced water consumption and sewage production (***l/l***)

continue on next page

Table 4.5 (continued)

Sectoral mitigation measures	Effect on additional objectives/concerns		
	Economic	**Social**	**Environmental**
Behavioural changes reducing energy demand	Energy security (***m/h***); less need for energy subsidies (***l/l***)		Reduced health and ecosystem impact (e.g., via improved indoor environmental conditions (***m/h***) and less outdoor air pollution (***r/h***))
Industry	*For possible upstream effects of low-carbon energy supply (incl. CCS), see Energy Supply and of biomass supply, see AFOLU.*		
Reduction of CO_2/non-CO_2 GHG emission intensity	Competitiveness and productivity (***m/h***)	Reduced health impact via reduced local air pollution and better working conditions (PFC from aluminium) (***m/m***)	Reduced ecosystem impact (via reduced local air and water pollution) (***m/m***); water conservation (***l/m***)
Technical energy efficiency improvements via new processes/technologies	Energy security (via lower energy intensity) (***m/m***); employment impact (***l/l***); competitiveness and productivity (***m/h***); technological spillovers in DCs (***l/l***)	Reduced health impact via reduced local pollution (***l/m***); new business opportunities (***m/m***); increased water availability and quality (***l/l***); improved safety, working conditions and job satisfaction (***m/m***)	Reduced ecosystem impact via reduced fossil fuel extraction (***l/l***) and reduced local pollution and waste (***m/m***)
Material efficiency of goods, recycling	Decreased national sales tax revenue in the medium term (***l/l***); employment impact (waste recycling) (***l/l***); competitiveness in manufacturing (***l/l***); new infrastructure for industrial clusters (***l/l***)	Reduced health impacts and safety concerns (***l/m***); new business opportunities (***m/m***) and reduced local conflicts (reduced resource extraction) (***l/m***)	Reduced ecosystem impact via reduced local air and water pollution and waste material disposal (***m/m***); reduced use of raw/virgin materials and natural resources implying reduced unsustainable resource mining (***l/l***)
Product demand reductions	Decreased national sales tax revenue in the medium term (***l/l***)	Increased wellbeing via diverse lifestyle choices (***l/l***)	Reduced post-consumption waste (***l/l***)
AFOLU	*Note: co-benefits and adverse side effects depend on the development context and the scale of the intervention (size).*		
Supply side: forestry, land-based agriculture, livestock, integrated systems and bioenergy Demand side: reduced losses in the food supply chain, changes in human diets and in demand for wood and forestry products	Mixed employment impact via entrepreneurship development (***m/h***), use of less labour-intensive technologies in agriculture (***m/m***); diversification of income sources and access to markets (***r/h***); additional income to sustainable landscape management (***m/h***); income concentration (***m/m***); energy security (resource sufficiency) (***m/h***); Innovative financing mechanisms for sustainable resource management (***m/h***); technology innovation and transfer (***m/m***)	Increased food-crops production through integrated systems and sustainable agriculture intensification (***r/m***); decreased food production (locally) due to large-scale monocultures of non-food crops (***r/l***); increased cultural habitats and recreational areas via (sustainable) forest management and conservation (***m/m***); improved human health and animal welfare (e.g., through less use of pesticides, reduced burning practices and agroforestry and silvo-pastoral systems) (***m/h***); human health impact related to burning practices (in agriculture or bioenergy) (***m/m***); mixed impacts on gender, intra- and inter-generational equity via participation and fair benefit sharing (***r/h***) and higher concentration of benefits (***m/m***)	Mixed impact on ecosystem services via large-scale monocultures (***r/h***), ecosystem conservation, sustainable management as well as sustainable agriculture (***r/h***); increased land use competition (***r/m***); increased soil quality (***r/h***); decreased erosion (***r/h***); increased ecosystem resilience (***m/h***); albedo and evaporation (***r/h***) Institutional aspects: mixed impact on tenure and use rights at the local level (for indigenous people and local communities) (***r/h***) and on access to participative mechanisms for land management decisions (***r/h***); enforcement of existing policies for sustainable resource management (***r/h***)
Human Settlements and Infrastructure	*For compact urban form and improved transport infrastructure, see also Transport.*		
Compact development and infrastructure	Increased innovation and efficient resource use (***r/h***); higher rents and property values (***m/m***)	Improved health from increased physical activity: *see Transport*	Preservation of open space (***m/m***)
Increased accessibility	Commute savings (***r/h***)	Improved health from increased physical activity: *see Transport*; increased social interaction and mental health (***m/m***)	Improved air quality and reduced ecosystem and health impacts (***m/h***)
Mixed land use	Commute savings (***r/h***); higher rents and property values (***m/m***)	Improved health from increased physical activity (***r/h***); social interaction and mental health (***l/m***)	Improved air quality and reduced ecosystem and health impacts (***m/h***)



Loose coordination of policies: examples include transnational city networks and Nationally Appropriate Mitigation Actions (NAMAs); R&D technology cooperation: examples include the Major Economies Forum on Energy and Climate (MEF), Global Methane Initiative (GMI), or Renewable Energy and Energy Efficiency Partnership (REEEP); Other international organization (IO) GHG regulation: examples include the Montreal Protocol, International Civil Aviation Organization (ICAO), International Maritime Organization (IMO); See WGIII Figure 13.1 for the details of these examples.

Figure 4.3 | Alternative forms of international cooperation. The figure represents a compilation of existing and possible forms of international cooperation, based upon a survey of published research, but is not intended to be exhaustive of existing or potential policy architectures, nor is it intended to be prescriptive. Examples in orange are existing agreements. Examples in blue are structures for agreements proposed in the literature. The width of individual boxes indicates the range of possible degrees of centralization for a particular agreement. The degree of centralization indicates the authority an agreement confers on an international institution, not the process of negotiating the agreement. *{WGIII Figure 13.2}*

While a number of new institutions are focused on adaptation funding and coordination, adaptation has historically received less attention than mitigation in international climate policy (*robust evidence, medium agreement*). Inclusion of adaptation is increasingly important to reduce the risk from climate change impacts and may engage a greater number of countries. *{WGIII 13.2, 13.3.3, 13.5.1.1, 13.14}*

The Kyoto Protocol offers lessons towards achieving the ultimate objective of the UNFCCC, particularly with respect to participation, implementation, flexibility mechanisms, and environmental effectiveness (*medium evidence, low agreement*). The Protocol was the first binding step toward implementing the principles and goals provided by the UNFCCC. According to national GHG inventories through 2012 submitted to the UNFCCC by October 2013, Annex B Parties with quantified emission limitations (and reduction obligations) in aggregate may have bettered their collective emission reduction target in the first commitment period,[44] but some emissions reductions that would have occurred even in its absence were also counted. The Protocol's Clean Development Mechanism (CDM) created a market for emissions offsets from developing countries, the purpose being two-fold: to help Annex I countries fulfill their commitments and to assist non-Annex I countries achieve sustainable development. The CDM generated Certified Emission Reductions (offsets) equivalent to emissions of over 1.4 $GtCO_2$-eq[42] by October 2013, led to significant project investments, and generated investment flows for a variety of functions, including the UNFCCC Adaptation Fund. However, its environmental effectiveness has been questioned by some, particularly

[44] The final conclusion regarding compliance of Annex B Parties remains subject to the review process under the Kyoto Protocol as of October 2014.

in regard to its early years, due to concerns about the additionality of projects (that is, whether projects bring about emissions that are different from business as usual (BAU) circumstances), the validity of baselines, and the possibility of emissions leakage (*medium evidence, medium agreement*). Such concerns about additionality are common to any emission-reduction-credit (offset) program, and are not specific to the CDM. Due to market forces, the majority of single CDM projects have been concentrated in a limited number of countries, while Programmes of Activities, though less frequent, have been more evenly distributed. In addition, the Kyoto Protocol created two other 'flexibility mechanisms': Joint Implementation and International Emissions Trading. *{WGIII SPM.5.2, Table TS.9, 13.7, 13.13.1.1, 14.3}*

Several conceptual models for effort-sharing have been identified in research. However, realized distributional impacts from actual international cooperative agreements depend not only on the approach taken but also on criteria applied to operationalize equity and the manner in which developing countries' emissions reduction plans are financed. *{WGIII 4.6, 13.4}*

Policy linkages among regional, national and sub-national climate policies offer potential climate change mitigation benefits (*medium evidence, medium agreement*). Linkages have been established between carbon markets and in principle could also be established between and among a heterogeneous set of policy instruments including non-market-based policies, such as performance standards. Potential advantages include lower mitigation costs, decreased emission leakage and increased market liquidity. *{WGIII SPM.5.2, 13.3, 13.5, 13.6, 13.7, 14.5}*

Regional initiatives between national and global scales are being developed and implemented, but their impact on global mitigation has been limited to date (*medium confidence*). Some climate policies could be more environmentally and economically effective if implemented across broad regions, such as by embodying mitigation objectives in trade agreements or jointly constructing infrastructures that facilitate reduction in carbon emissions. *{WGIII Table TS.9, 13.13, 14.4, 14.5}*

International cooperation for supporting adaptation planning and implementation has assisted in the creation of adaptation strategies, plans and actions at national, sub-national and local levels (*high confidence*). For example, a range of multilateral and regionally targeted funding mechanisms have been established for adaptation; UN agencies, international development organizations and non-governmental organisations (NGOs) have provided information, methodologies and guidelines; and global and regional initiatives supported and promoted the creation of national adaptation strategies in both developing and developed countries. Closer integration of disaster risk reduction and climate change adaptation at the international level, and the mainstreaming of both into international development assistance, may foster greater efficiency in the use of resources and capacity. However, stronger efforts at the international level do not necessarily lead to substantive and rapid results at the local level. *{WGII 15.2, 15.3, SREX SPM, 7.4, 8.2, 8.5}*

4.4.2 National and sub-national policies

4.4.2.1 Adaptation

Adaptation experience is accumulating across regions in the public and private sector and within communities (*high confidence*). Adaptation options adopted to date (see Table 4.6) emphasize incremental adjustments and co-benefits and are starting to emphasize flexibility and learning (*medium evidence, medium agreement*). Most assessments of adaptation have been restricted to impacts, vulnerability and adaptation planning, with very few assessing the processes of implementation or the effects of adaptation actions (*medium evidence, high agreement*). *{WGII SPM A-2, TS A-2}*

Table 4.6 | Recent adaptation actions in the public and private sector across regions. *{WGII SPM A-2}*

Region	Example of actions
Africa	Most national governments are initiating governance systems for adaptation. Disaster risk management, adjustments in technologies and infrastructure, ecosystem-based approaches, basic public health measures and livelihood diversification are reducing vulnerability, although efforts to date tend to be isolated.
Europe	Adaptation policy has been developed across all levels of government, with some adaptation planning integrated into coastal and water management, into environmental protection and land planning and into disaster risk management.
Asia	Adaptation is being facilitated in some areas through mainstreaming climate adaptation action into sub-national development planning, early warning systems, integrated water resources management, agroforestry and coastal reforestation of mangroves.
Australasia	Planning for sea level rise, and in southern Australia for reduced water availability, is becoming adopted widely. Planning for sea level rise has evolved considerably over the past two decades and shows a diversity of approaches, although its implementation remains piecemeal.
North America	Governments are engaging in incremental adaptation assessment and planning, particularly at the municipal level. Some proactive adaptation is occurring to protect longer-term investments in energy and public infrastructure.
Central and South America	Ecosystem-based adaptation including protected areas, conservation agreements and community management of natural areas is occurring. Resilient crop varieties, climate forecasts and integrated water resources management are being adopted within the agricultural sector in some areas.
The Arctic	Some communities have begun to deploy adaptive co-management strategies and communications infrastructure, combining traditional and scientific knowledge.
Small Islands	Small islands have diverse physical and human attributes; community-based adaptation has been shown to generate larger benefits when delivered in conjunction with other development activities.
The Ocean	International cooperation and marine spatial planning are starting to facilitate adaptation to climate change, with constraints from challenges of spatial scale and governance issues.

National governments play key roles in adaptation planning and implementation (*robust evidence, high agreement*). There has been substantial progress since the AR4 in the development of national adaptation strategies and plans. This includes National Adaptation Programmes of Action (NAPAs) by least developed countries, the National Adaptation Plan (NAP) process, and strategic frameworks for national adaptation in Organisation for Economic Co-operation and Development (OECD) countries. National governments can coordinate adaptation efforts of local and sub-national governments, for example by protecting vulnerable groups, by supporting economic diversification, and by providing information, policy and legal frameworks and financial support. *{WGII SPM C-1, 15.2}*

While local government and the private sector have different functions, which vary regionally, they are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing (*medium evidence, high agreement*). There is a significant increase in the number of planned adaptation responses at the local level in rural and urban communities of developed and developing countries since the AR4. However, local councils and planners are often confronted by the complexity of adaptation without adequate access to guiding information or data on local vulnerabilities and potential impacts. Steps for mainstreaming adaptation into local decision-making have been identified but challenges remain in their implementation. Hence, scholars stress the important role of linkages with national and sub-national levels of government as well as partnerships among public, civic and private sectors in implementing local adaptation responses. *{WGII SPM A-2, SPM C-1, 14.2, 15.2}*

Institutional dimensions of adaptation governance, including the integration of adaptation into planning and decision-making, play a key role in promoting the transition from planning to implementation of adaptation (*robust evidence, high agreement*). The most commonly emphasized institutional barriers or enablers for adaptation planning and implementation are: 1) multilevel institutional co-ordination between different political and administrative levels in society; 2) key actors, advocates and champions initiating, mainstreaming and sustaining momentum for climate adaptation; 3) horizontal interplay between sectors, actors and policies operating at similar administrative levels; 4) political dimensions in planning and implementation; and 5) coordination between formal governmental, administrative agencies and private sectors and stakeholders to increase efficiency, representation and support for climate adaptation measures. *{WGII 15.2, 15.5, 16.3, Box 15-1}*

Existing and emerging economic instruments can foster adaptation by providing incentives for anticipating and reducing impacts (*medium confidence*). Instruments include public-private finance partnerships, loans, payments for environmental services, improved resource pricing, charges and subsidies, norms and regulations and risk sharing and transfer mechanisms. Risk financing mechanisms in the public and private sector, such as insurance and risk pools, can contribute to increasing resilience, but without attention to major design challenges, they can also provide disincentives, cause market failure and decrease equity. Governments often play key roles as regulators, providers or insurers of last resort. *{WGII SPM C-1}*

4.4.2.2 Mitigation

There has been a considerable increase in national and sub-national mitigation plans and strategies since AR4. In 2012, 67% of global GHG emissions[42] were subject to national legislation or strategies versus 45% in 2007. However, there has not yet been a substantial deviation in global emissions from the past trend. These plans and strategies are in their early stages of development and implementation in many countries, making it difficult to assess their aggregate impact on future global emissions (*medium evidence, high agreement*). *{WGIII SPM.5.1}*

Since AR4, there has been an increased focus on policies designed to integrate multiple objectives, increase co-benefits and reduce adverse side effects (*high confidence*). Governments often explicitly reference co-benefits in climate and sectoral plans and strategies. *{WGIII SPM.5.1}*

Sector-specific policies have been more widely used than economy-wide policies (Table 4.7) (*medium evidence, high agreement*). Although most economic theory suggests that economy-wide policies for mitigation would be more cost-effective than sector-specific policies, administrative and political barriers may make economy-wide policies harder to design and implement than sector-specific policies. The latter may be better suited to address barriers or market failures specific to certain sectors and may be bundled in packages of complementary policies *{WGIII SPM.5.1}*

In principle, mechanisms that set a carbon price, including cap and trade systems and carbon taxes, can achieve mitigation in a cost-effective way, but have been implemented with diverse effects due in part to national circumstances as well as policy design. The short-run environmental effects of cap and trade systems have been limited as a result of loose caps or caps that have not proved to be constraining (*limited evidence, medium agreement*). In some countries, tax-based policies specifically aimed at reducing GHG emissions—alongside technology and other policies—have helped to weaken the link between GHG emissions and gross domestic product (GDP) (*high confidence*). In addition, in a large group of countries, fuel taxes (although not necessarily designed for the purpose of mitigation) have had effects that are akin to sectoral carbon taxes (*robust evidence, medium agreement*). Revenues from carbon taxes or auctioned emission allowances are used in some countries to reduce other taxes and/or to provide transfers to low-income groups. This illustrates the general principle that mitigation policies that raise government revenue generally have lower social costs than approaches which do not. *{WGIII SPM.5.1}*

Economic instruments in the form of subsidies may be applied across sectors, and include a variety of policy designs, such as tax rebates or exemptions, grants, loans and credit lines. An increasing number and variety of RE policies including subsidies—motivated by many factors—have driven escalated growth of RE technologies in recent years. Government policies play a crucial role in accelerating the deployment of RE technologies. Energy access and social and economic development have been the primary drivers in most developing countries whereas secure energy supply and environmental concerns have been most important in developed countries. The focus of policies is

Table 4.7 | Sectoral Policy Instruments. *{WGIII Table 15.2}*

Policy Instruments	Energy	Transport	Buildings	Industry	AFOLU	Human Settlements and Infrastructure
Economic Instruments – Taxes (carbon taxes may be economy-wide)	- Carbon tax (e.g., applied to electricity or fuels)	- Fuel taxes - Congestion charges, vehicle registration fees, road tolls - Vehicle taxes	- Carbon and/or energy taxes (either sectoral or economy-wide)	- Carbon tax or energy tax - Waste disposal taxes or charges	- Fertilizer or nitrogen taxes to reduce nitrous oxide (N_2O)	- Sprawl taxes, Impact fees, exactions, split-rate property taxes, tax increment finance, betterment taxes, congestion charges
Economic Instruments – Tradable Allowances (may be economy-wide)	- Emission trading - Emission credits under the Clean Development Mechanism (CDM) - Tradable Green Certificates	- Fuel and vehicle standards	- Tradable certificates for energy efficiency improvements (white certificates)	- Emission trading - Emission credits under CDM - Tradable Green Certificates	- Emission credits under CDM - Compliance schemes outside Kyoto protocol (national schemes) - Voluntary carbon markets	- Urban-scale cap and trade
Economic Instruments – Subsidies	- Fossil fuel subsidy removal - Feed in tariffs (FITs) for renewable energy	- Biofuel subsidies - Vehicle purchase subsidies - Feebates	- Subsidies or tax exemptions for investment in efficient buildings, retrofits and products - Subsidized loans	- Subsidies (e.g., for energy audits) - Fiscal incentives (e.g., for fuel switching)	- Credit lines for low-carbon agriculture, sustainable forestry	- Special Improvement or Redevelopment Districts
Regulatory Approaches	- Efficiency or environmental performance standards - Renewable Portfolio Standards (RPS) for renewable energy (RE) - Equitable access to electricity grid - Legal status of long-term CO_2 storage	- Fuel economy performance standards - Fuel quality standards - Greenhouse gas (GHG) emission performance standards - Regulatory restrictions to encourage modal shifts (road to rail) - Restriction on use of vehicles in certain areas - Environmental capacity constraints on airports - Urban planning and zoning restrictions	- Building codes and standards - Equipment and appliance standards - Mandates for energy retailers to assist customers invest in energy efficiency	- Energy efficiency standards for equipment - Energy management systems (also voluntary) - Voluntary agreements (where bound by regulation) - Labelling and public procurement regulations	- National policies to support REDD+ including monitoring, reporting and verification - Forest laws to reduce deforestation - Air and water pollution control GHG precursors - Land use planning and governance	- Mixed use zoning - Development restrictions - Affordable housing mandates - Site access controls - Transfer development rights - Design codes - Building codes - Street codes - Design standards
Information Programmes		- Fuel labelling - Vehicle efficiency labelling	- Energy audits - Labelling programmes - Energy advice programmes	- Energy audits - Benchmarking - Brokerage for industrial cooperation	- Certification schemes for sustainable forest practices - Information policies to support REDD+ including monitoring, reporting and verification	
Government Provision of Public Goods or Services	- Research and development - Infrastructure expansion (district heating/cooling or common carrier)	- Investment in transit and human powered transport - Investment in alternative fuel infrastructure - Low-emission vehicle procurement	- Public procurement of efficient buildings and appliances	- Training and education - Brokerage for industrial cooperation	- Protection of national, state, and local forests. - Investment in improvement and diffusion of innovative technologies in agriculture and forestry	- Provision of utility infrastructure, such as electricity distribution, district heating/cooling and wastewater connections, etc. - Park improvements - Trail improvements - Urban rail
Voluntary Actions			- Labelling programmes for efficient buildings - Product eco-labelling	- Voluntary agreements on energy targets, adoption of energy management systems, or resource efficiency	- Promotion of sustainability by developing standards and educational campaigns	

broadening from a concentration primarily on RE electricity to include RE heating and cooling and transportation. *{SRREN SPM.7}*

The reduction of subsidies for GHG-related activities in various sectors can achieve emission reductions, depending on the social and economic context (*high confidence*). While subsidies can affect emissions in many sectors, most of the recent literature has focused on subsidies for fossil fuels. Since AR4 a small but growing literature based on economy-wide models has projected that complete removal of subsidies to fossil fuels in all countries could result in reductions in global aggregate emissions by mid-century (*medium evidence, medium agreement*). Studies vary in methodology, the type and definition of subsidies and the time frame for phase out considered. In particular, the studies assess the impacts of complete removal of all fossil fuel subsides without seeking to assess which subsidies are wasteful and inefficient, keeping in mind national circumstances. *{WGIII SPM.5.1}*

Regulatory approaches and information measures are widely used and are often environmentally effective (*medium evidence, medium agreement*). Examples of regulatory approaches include energy efficiency standards; examples of information programmes include labelling programmes that can help consumers make better-informed decisions. *{WGIII SPM.5.1}*

Mitigation policy could devalue fossil fuel assets and reduce revenues for fossil fuel exporters, but differences between regions and fuels exist (*high confidence*). Most mitigation scenarios are associated with reduced revenues from coal and oil trade for major exporters. The effect on natural gas export revenues is more uncertain. The availability of CCS would reduce the adverse effect of mitigation on the value of fossil fuel assets (*medium confidence*). *{WGIII SPM.5.1}*

Interactions between or among mitigation policies may be synergistic or may have no additive effect on reducing emissions (*medium evidence, high agreement*). For instance, a carbon tax can have an additive environmental effect to policies such as subsidies for the supply of RE. By contrast, if a cap and trade system has a sufficiently stringent cap to affect emission-related decisions, then other policies have no further impact on reducing emissions (although they may affect costs and possibly the viability of more stringent future targets) (*medium evidence, high agreement*). In either case, additional policies may be needed to address market failures relating to innovation and technology diffusion. *{WGIII SPM.5.1}*

Sub-national climate policies are increasingly prevalent, both in countries with national policies and in those without. These policies include state and provincial climate plans combining market, regulatory and information instruments, and sub-national cap-and-trade systems. In addition, transnational cooperation has arisen among sub-national actors, notably among institutional investors, NGOs seeking to govern carbon offset markets, and networks of cities seeking to collaborate in generating low-carbon urban development. *{WGIII 13.5.2, 15.2.4, 15.8}*

Co-benefits and adverse side effects of mitigation could affect achievement of other objectives such as those related to human health, food security, biodiversity, local environmental quality, energy access, livelihoods and equitable sustainable development: *{WGIII SPM.2}*

- Mitigation scenarios reaching about 450 or 500 ppm CO_2-equivalent by 2100 show reduced costs for achieving air quality and energy security objectives, with significant co-benefits for human health, ecosystem impacts and sufficiency of resources and resilience of the energy system. *{WGIII SPM.4.1}*

- Some mitigation policies raise the prices for some energy services and could hamper the ability of societies to expand access to modern energy services to underserved populations (*low confidence*). These potential adverse side effects can be avoided with the adoption of complementary policies such as income tax rebates or other benefit transfer mechanisms (*medium confidence*). The costs of achieving nearly universal access to electricity and clean fuels for cooking and heating are projected to be between USD 72 to 95 billion per year until 2030 with minimal effects on GHG emissions (*limited evidence, medium agreement*) and multiple benefits in health and air pollutant reduction (*high confidence*). *{WGIII SPM.5.1}*

Whether or not side effects materialize, and to what extent side effects materialize, will be case- and site-specific, and depend on local circumstances and the scale, scope and pace of implementation. Many co-benefits and adverse side effects have not been well-quantified. *{WGIII SPM.4.1}*

4.4.3 Technology development and transfer

Technology policy (development, diffusion and transfer) complements other mitigation policies across all scales from international to sub-national, but worldwide investment in research in support of GHG mitigation is small relative to overall public research spending (*high confidence*). Technology policy includes technology-push (e.g., publicly-funded R&D) and demand-pull (e.g., governmental procurement programmes). Such policies address a pervasive market failure because, in the absence of government policy such as patent protection, the invention of new technologies and practices from R&D efforts has aspects of a public good and thus tends to be under-provided by market forces alone. Technology support policies have promoted substantial innovation and diffusion of new technologies, but the cost-effectiveness of such policies is often difficult to assess. Technology policy can increase incentives for participation and compliance with international cooperative efforts, particularly in the long run. *{WGIII SPM.5.1, 2.6.5, 3.11, 13.9, 13.12, 15.6.5}*

Many adaptation efforts also critically rely on diffusion and transfer of technologies and management practices, but their effective use depends on a suitable institutional, regulatory, social and cultural context (*high confidence*). Adaptation technologies are often familiar and already applied elsewhere. However, the success of technology transfer may involve not only the provision of finance and information, but also strengthening of policy and regulatory environments and capacities to absorb, employ and improve technologies appropriate to local circumstances. *{WGII 15.4}*

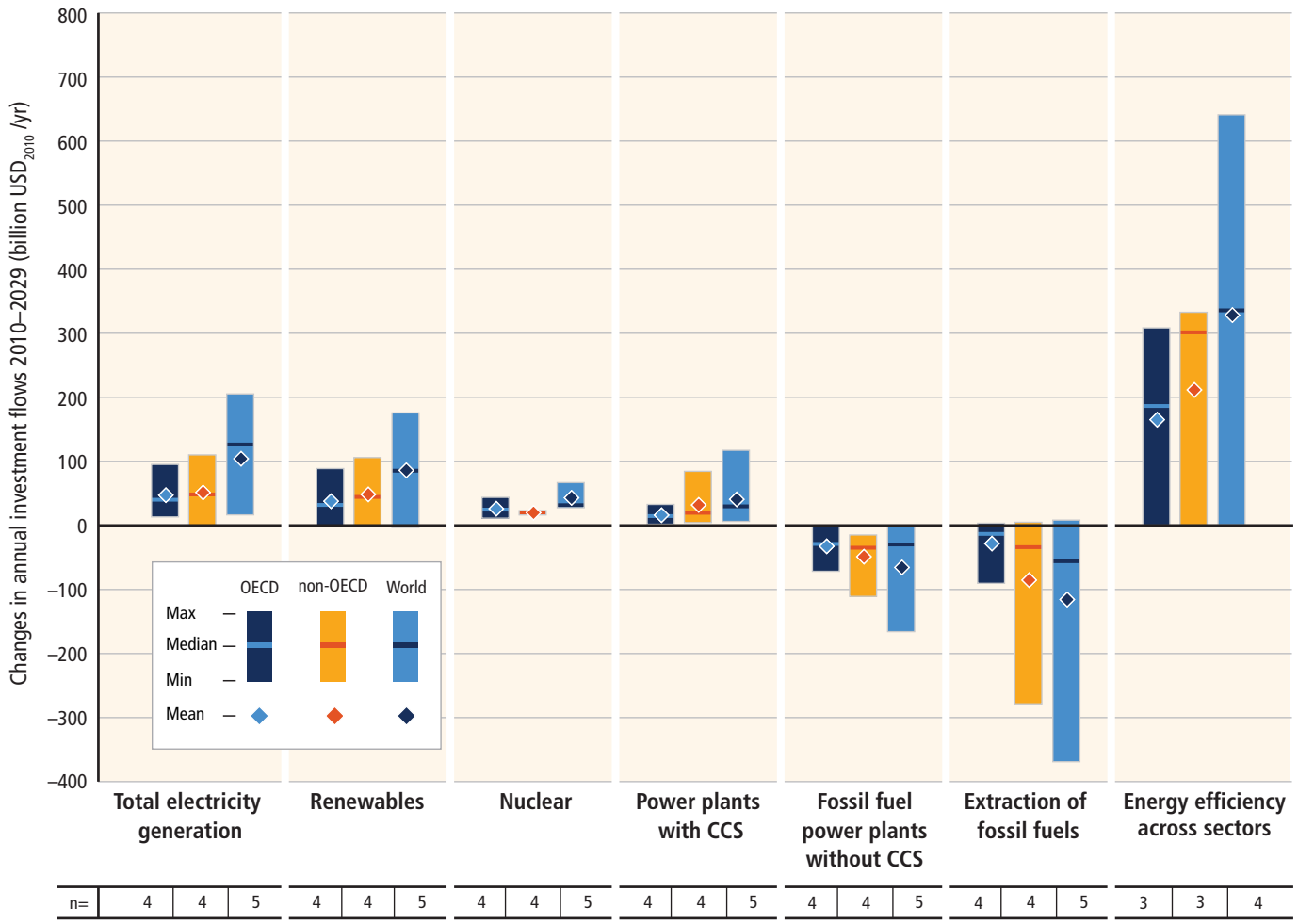


Figure 4.4 | Change in annual investment flows from the average baseline level over the next two decades (2010 to 2029) for mitigation scenarios that stabilize concentrations (without overshoot) within the range of approximately 430 to 530 ppm CO_2-eq by 2100. Total electricity generation (leftmost column) is the sum of renewable and nuclear energy, power plants with CCS, and fossil-fuel power plants without CCS. The vertical bars indicate the range between the minimum and maximum estimate; the horizontal bar indicates the median. The numbers in the bottom row show the total number of studies in the literature used in the assessment. Individual technologies shown are found to be used in different model scenarios in either a complementary or a synergistic way, depending largely on technology-specific assumptions and the timing and ambition level of the phase-in of global climate policies. *{WGIII Figure SPM.9}*

4

4.4.4 Investment and finance

Substantial reductions in emissions would require large changes in investment patterns (*high confidence*). Mitigation scenarios in which policies stabilize atmospheric concentrations (without overshoot) in the range from 430 to 530 ppm CO_2-eq by 2100[45] lead to substantial shifts in annual investment flows during the period 2010–2029 compared to baseline scenarios. Over the next two decades (2010–2029), annual investments in conventional fossil fuel technologies associated with the electricity supply sector are projected to decline in the scenarios by about USD 30 (2 to 166) billion (median: –20% compared to 2010) while annual investment in low carbon electricity supply (i.e., renewables, nuclear and electricity with CCS) is projected to rise in the scenarios by about USD 147 (31 to 360) billion (median: +100% compared to 2010) (*limited evidence, medium agreement*). In addition, annual incremental energy efficiency investments in transport, industry and buildings is projected to rise in the scenarios by about USD 336 (1 to 641) billion. Global total annual investment in the energy system is presently about USD 1,200 billion. This number includes only energy supply of electricity and heat and respective upstream and downstream activities. Energy efficiency investment or underlying sector investment is not included (Figure 4.4). *{WGIII SPM.5.1, 16.2}*

There is no widely agreed definition of what constitutes climate finance, but estimates of the financial flows associated with climate change mitigation and adaptation are available. See Figure 4.5 for an overview of climate finance flows. Published assessments of all current annual financial flows whose expected effect is to reduce net GHG emissions and/or to enhance resilience to climate change and climate variability show USD 343 to 385 billion per year

[45] This range comprises scenarios that reach 430 to 480 ppm CO_2-eq by 2100 (*likely* to limit warming to 2°C above pre-industrial levels) and scenarios that reach 480 to 530 ppm CO_2-eq by 2100 (without overshoot: *more likely than not* to limit warming to 2°C above pre-industrial levels).

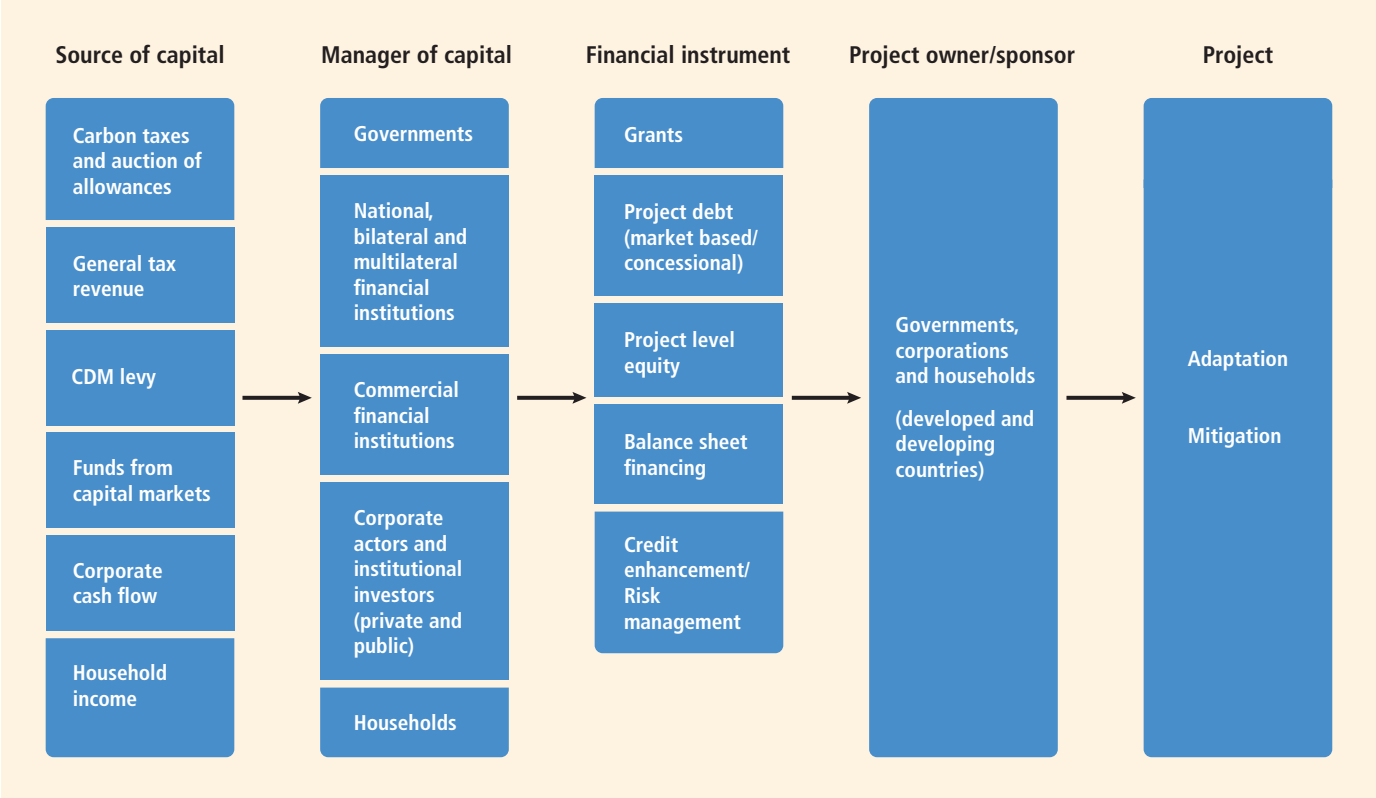


Figure 4.5 | Overview of climate finance flows. Note: Capital should be understood to include all relevant financial flows. The size of the boxes is not related to the magnitude of the financial flow. *{WGIII Figure TS.40}*

globally (*medium confidence*). Out of this, total public climate finance that flowed to developing countries is estimated to be between USD 35 and 49 billion per year in 2011 and 2012 (*medium confidence*). Estimates of international private climate finance flowing to developing countries range from USD 10 to 72 billion per year including foreign direct investment as equity and loans in the range of USD 10 to 37 billion per year over the period of 2008–2011 (*medium confidence*). *{WGIII SPM.5.1}*

In many countries, the private sector plays central roles in the processes that lead to emissions as well as to mitigation and adaptation. Within appropriate enabling environments, the private sector, along with the public sector, can play an important role in financing mitigation and adaptation (*medium evidence, high agreement*). The share of total mitigation finance from the private sector, acknowledging data limitations, is estimated to be on average between two-thirds and three-fourths on the global level (2010–2012) (*limited evidence, medium agreement*). In many countries, public finance interventions by governments and international development banks encourage climate investments by the private sector and provide finance where private sector investment is limited. The quality of a country's enabling environment includes the effectiveness of its institutions, regulations and guidelines regarding the private sector, security of property rights, credibility of policies and other factors that have a substantial impact on whether private firms invest in new technologies and infrastructures. Dedicated policy instruments and financial arrangements, for example, credit insurance, feed-in tariffs, concessional finance or rebates provide an incentive for mitigation investment by improving the return adjusted for the risk for private actors. Public-private risk reduction initiatives (such as in the context of insurance systems) and economic diversification are examples of adaptation action enabling and relying on private sector participation. *{WGII SPM B-2, SPM C-1, WGIII SPM.5.1}*

Financial resources for adaptation have become available more slowly than for mitigation in both developed and developing countries. Limited evidence indicates that there is a gap between global adaptation needs and the funds available for adaptation (*medium confidence*). Potential synergies between international finance for disaster risk management and adaptation to climate change have not yet been fully realized (*high confidence*). There is a need for better assessment of global adaptation costs, funding and investment. Studies estimating the global cost of adaptation are characterized by shortcomings in data, methods and coverage (*high confidence*). *{WGII SPM C-1, 14.2, SREX SPM}*

4.5 Trade-offs, synergies and integrated responses

There are many opportunities to link mitigation, adaptation and the pursuit of other societal objectives through integrated responses (*high confidence*). Successful implementation relies on relevant tools, suitable governance structures and enhanced capacity to respond (*medium confidence*).

A growing evidence base indicates close links between adaptation and mitigation, their co-benefits and adverse side effects, and recognizes sustainable development as the overarching context for climate policy (see Sections 3.5, 4.1, 4.2 and 4.3). Developing tools to address these linkages is critical to the success of climate policy in the context of sustainable development (see also Sections 4.4 and 3.5). This section presents examples of integrated responses in specific policy arenas, as well as some of the factors that promote or impede policies aimed at multiple objectives.

Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, encompassing connections among human health, water, energy, land use and biodiversity (*very high confidence*). Mitigation can support the achievement of other societal goals, such as those related to human health, food security, environmental quality, energy access, livelihoods and sustainable development, although there can also be negative effects. Adaptation measures also have the potential to deliver mitigation co-benefits, and vice versa, and support other societal goals, though trade-offs can also arise. *{WGII SPM C-1, SPM C-2, 8.4, 9.3–9.4, 11.9, Box CC-WE, WGIII Table TS.3, Table TS.4, Table TS.5, Table TS.6, Table TS.7}*

Integration of adaptation and mitigation into planning and decision-making can create synergies with sustainable development (*high confidence*). Synergies and trade-offs among mitigation and adaptation policies and policies advancing other societal goals can be substantial, although sometimes difficult to quantify especially in welfare terms (see also Section 3.5). A multi-objective approach to policy-making can help manage these synergies and trade-offs. Policies advancing multiple goals may also attract greater support. *{WGII SPM C-1, SPM C-2, 20.3, WGIII 1.2.1, 3.6.3, 4.3, 4.6, 4.8, 6.6.1}*

Effective integrated responses depend on suitable tools and governance structures, as well as adequate capacity (*medium confidence*). Managing trade-offs and synergies is challenging and requires tools to help understand interactions and support decision-making at local and regional scales. Integrated responses also depend on governance that enables coordination across scales and sectors, supported by appropriate institutions. Developing and implementing suitable tools and governance structures often requires upgrading the human and institutional capacity to design and deploy integrated responses. *{WGII SPM C-1, SPM C-2, 2.2, 2.4, 15.4, 15.5, 16.3, Table 14-1, Table 16-1, WGIII TS.1, TS.3, 15.2}*

An integrated approach to energy planning and implementation that explicitly assesses the potential for co-benefits and the presence of adverse side effects can capture complementarities across multiple climate, social and environmental objectives (*medium confidence*). There are strong interactive effects across various energy policy objectives, such as energy security, air quality, health and energy access (see Figure 3.5) and between a range of social and environmental objectives and climate mitigation objectives (see Table 4.5). An integrated approach can be assisted by tools such as cost-benefit analysis, cost-effectiveness analysis, multi-criteria analysis and expected utility theory. It also requires appropriate coordinating institutions. *{WGIII Figure SPM.6, TS.1, TS.3}*

Explicit consideration of interactions among water, food, energy and biological carbon sequestration plays an important role in supporting effective decisions for climate resilient pathways (*medium evidence, high agreement*). Both biofuel-based power generation and large-scale afforestation designed to mitigate climate change can reduce catchment run-off, which may conflict with alternative water uses for food production, human consumption or the maintenance of ecosystem function and services (see also Box 3.4). Conversely, irrigation can increase the climate resilience of food and fibre production but reduces water availability for other uses. *{WGII Box CC-WE, Box TS.9}*

An integrated response to urbanization provides substantial opportunities for enhanced resilience, reduced emissions and more sustainable development (*medium confidence*). Urban areas account for more than half of global primary energy use and energy-related CO_2 emissions (*medium evidence, high agreement*) and contain a high proportion of the population and economic activities at risk from climate change. In rapidly growing and urbanizing regions, mitigation strategies based on spatial planning and efficient infrastructure supply can avoid the lock-in of high emission patterns. Mixed-use zoning, transport-oriented development, increased density and co-located jobs and homes can reduce direct and indirect energy use across sectors. Compact development of urban spaces and intelligent densification can preserve land carbon stocks and land for agriculture and bioenergy. Reduced energy and water consumption in urban areas through greening cities and recycling water are examples of mitigation actions with adaptation benefits. Building resilient infrastructure systems can reduce vulnerability of urban settlements and cities to coastal flooding, sea level rise and other climate-induced stresses. *{WGII SPM B-2, SPM C-1, TS B-2, TS C-1, TS C-2, WGIII SPM.4.2.5, TS.3}*

Annexes

ANNEX I

User Guide

I

User Guide

As defined in the IPCC Procedures, the Synthesis Report (SYR) synthesises and integrates material contained within IPCC Assessment Reports and Special Reports. The scope of the SYR of the Fifth Assessment Report (AR5) includes material contained in the three Working Group contributions to the AR5, and it draws on information contained in other IPCC Reports as required. The SYR is based exclusively on assessments by the IPCC Working Groups; it does not refer to or assess the primary scientific literature itself.

The SYR is a self-contained, condensed summary of the much richer information contained in the underlying Working Group Reports. Users may wish to access relevant material at the required level of detail in the following manner: the report contains a Summary for Policymakers (SPM) that provides the most condensed summary of the current understanding of scientific, technical and socio-economic aspects of climate change. All references in curly brackets in this SPM refer to sections in the longer report. The longer report consists of an Introduction and four Topics. The numbers of the SPM sections largely correspond with the section numbers of the Topics. At the end of each paragraph, references are provided in italics between curly brackets. These refer to the Summaries for Policymakers (SPMs), Technical Summaries (TSs), Executive Summaries of chapters (ESs) and chapters (with chapter and section numbers) of the underlying Working Group contributions to the AR5 and Special Reports of the AR5. References to the IPCC Fourth Assessment Report (AR4) in 2007 are identified by adding "AR4" to the reference.

Users who wish to gain a better understanding of scientific details or access the primary scientific literature on which the SYR is based should refer to chapter sections of the underlying Working Group reports that are cited in the longer report of the SYR. The individual chapters of the Working Group reports provide references to the primary scientific literature on which IPCC assessments are based, and also offer the most detailed region- and sector-specific information.

A glossary, a list of acronyms, lists of authors and reviewers, a list of IPCC publications (annexes) and an index are provided to further facilitate the use of this report.

ANNEX II

Glossary

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This annex should be cited as:

IPCC, 2014: Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

This glossary defines some specific terms as the Core Writing Team of the Synthesis Report intends them to be interpreted in the context of this report. Red, italicized words indicate that the term is defined in the glossary. The references to Working Groups (WG) I, II and III in italics at the end of each term in this glossary refer to the AR5 WG glossaries and should be read as: WGI (IPCC, 2013a), WGII (IPCC, 2014a), and WGIII (IPCC, 2014b).

Abrupt change/abrupt climate change
Abrupt change refers to a change that is substantially faster than the rate of change in the recent history of the affected components of a system. Abrupt *climate change* refers to a large-scale change in the *climate system* that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades and causes substantial disruptions in human and natural systems. *{WGI, II, III}*

Adaptation
The process of adjustment to actual or expected *climate* and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected *climate* and its effects[1]. *{WGII, III}*

Adaptation deficit
The gap between the current state of a system and a state that minimizes adverse *impacts* from existing *climate* conditions and variability. *{WGII}*

Adaptation limit
The point at which an actor's objectives (or system needs) cannot be secured from intolerable *risks* through adaptive actions. *{WGII}*

Hard adaptation limit
No adaptive actions are possible to avoid intolerable *risks*.

Soft adaptation limit
Options are currently not available to avoid intolerable *risks* through adaptive action.

Adaptive capacity
The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences[2]. *{WGII, III}*

Adverse side effects
The negative effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare. Adverse side effects are often subject to *uncertainty* and depend on local circumstances and implementation practices, among other factors. See also *Co-benefits* and *Risk*. *{WGIII}*

Afforestation
Planting of new *forests* on lands that historically have not contained *forests*. For a discussion of the term *forest* and related terms such as *afforestation*, *reforestation* and *deforestation*, see the IPCC Special Report on Land Use, Land-Use Change, and Forestry (IPCC, 2000b). See also information provided by the United Nations Framework Convention on Climate Change (UNFCCC, 2013) and the report on Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types (IPCC, 2003). *{WGI, III}*

Agriculture, Forestry and Other Land Use (AFOLU and FOLU/LULUCF)
AFOLU plays a central role for *food security* and *sustainable development*. The main *mitigation* options within AFOLU involve one or more of three strategies: prevention of emissions to the atmosphere by conserving existing carbon pools in soils or vegetation or by reducing emissions of methane and nitrous oxide; *sequestration*—increasing the size of existing carbon pools and thereby extracting carbon dioxide (CO_2) from the atmosphere; and substitution—substituting biological products for fossil fuels or energy-intensive products, thereby reducing CO_2 emissions. Demand-side measures (e.g., reducing losses and wastes of food, changes in human diet, or changes in wood consumption) may also play a role.

FOLU (Forestry and Other Land Use)—also referred to as LULUCF (Land Use, Land-Use Change, and Forestry)—is the subset of AFOLU emissions and removals of greenhouse gases (GHGs) resulting from direct human-induced *land use, land-use change,* and forestry activities excluding agricultural emissions. *{WGIII}*

Albedo
The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo, the albedo of soils ranges from high to low and vegetation-covered surfaces and oceans have a low albedo. The Earth's planetary albedo varies mainly through varying cloudiness, snow, ice, leaf area and land cover changes. *{WGI, III}*

Altimetry
A technique for measuring the height of the Earth's surface with respect to the geocentre of the Earth within a defined terrestrial reference frame (geocentric sea level). *{WGI}*

Ancillary benefits
See *Co-benefits*. *{WGII, III}*

Attribution
See *Detection and attribution*. *{WGI, II}.*

Baseline/reference
The baseline (or reference) is the state against which change is measured. A baseline period is the period relative to which anomalies are computed. In the context of *transformation pathways*, the term *baseline*

[1] Reflecting progress in science, this glossary entry differs in breadth and focus from the entry used in the Fourth Assessment Report and other IPCC reports.

[2] This glossary entry builds from definitions used in previous IPCC reports and the Millennium Ecosystem Assessment (MEA, 2005).

scenarios refers to scenarios that are based on the assumption that no *mitigation* policies or measures will be implemented beyond those that are already in force and/or are legislated or planned to be adopted. Baseline scenarios are not intended to be predictions of the future, but rather counterfactual constructions that can serve to highlight the level of emissions that would occur without further policy effort. Typically, baseline scenarios are then compared to *mitigation scenarios* that are constructed to meet different goals for greenhouse gas (GHG) emissions, atmospheric concentrations or temperature change. The term *baseline scenario* is used interchangeably with *reference scenario* and *no policy scenario*. In much of the literature the term is also synonymous with the term *business-as-usual (BAU) scenario*, although the term *BAU* has fallen out of favour because the idea of *business as usual* in century-long socio-economic *projections* is hard to fathom. See also *Emission scenario*, *Representative Concentration Pathways (RCPs)* and *SRES scenarios*. *{WGI, II, III}*

Biodiversity
The variability among living organisms from terrestrial, marine and other *ecosystems*. Biodiversity includes variability at the genetic, species and *ecosystem* levels[3]. *{WGII, III}*

Bioenergy and Carbon Dioxide Capture and Storage (BECCS)
The application of *Carbon Dioxide Capture and Storage (CCS)* technology to bioenergy conversion processes. Depending on the total life-cycle emissions, including total marginal consequential effects (from *indirect land-use change (iLUC)* and other processes), BECCS has the potential for net carbon dioxide (CO_2) removal from the atmosphere. See also *Sequestration*. *{WGIII}*

Burden sharing/effort sharing
In the context of *mitigation*, burden sharing refers to sharing the effort of reducing the sources or enhancing the *sinks* of greenhouse gases (GHGs) from historical or projected levels, usually allocated by some criteria, as well as sharing the cost burden across countries. *{WGIII}*

Cancún Agreements
A set of decisions adopted at the 16th Session of the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC), including the following, among others: the newly established Green Climate Fund (GCF), a newly established technology mechanism, a process for advancing discussions on *adaptation*, a formal process for reporting *mitigation* commitments, a goal of limiting global mean surface temperature increase to 2°C and an agreement on MRV—Measurement, Reporting and Verification for those countries that receive international support for their *mitigation* efforts. *{WGIII}*

Cancún Pledges
During 2010, many countries submitted their existing plans for controlling greenhouse gas (GHG) emissions to the Climate Change Secretariat and these proposals have now been formally acknowledged under the United Nations Framework Convention on Climate Change (UNFCCC). Developed countries presented their plans in the shape of economy-wide targets to reduce emissions, mainly up to 2020, while developing countries proposed ways to limit their growth of emissions in the shape of plans of action. *{WGIII}*

Carbon cycle
The term used to describe the flow of carbon (in various forms, e.g., as carbon dioxide (CO_2)) through the atmosphere, ocean, terrestrial and marine biosphere and lithosphere. In this report, the reference unit for the global carbon cycle is $GtCO_2$ or GtC (Gigatonne of carbon = 1 GtC = 10^{15} grams of carbon. This corresponds to 3.667 $GtCO_2$). *{WGI, II, III}*

Carbon Dioxide Capture and Storage (CCS)
A process in which a relatively pure stream of carbon dioxide (CO_2) from industrial and energy-related sources is separated (captured), conditioned, compressed and transported to a storage location for long-term isolation from the atmosphere. See also *Bioenergy and Carbon Dioxide Capture and Storage (BECCS)* and *Sequestration*. *{WGIII}*

Carbon Dioxide Removal (CDR)
Carbon Dioxide Removal methods refer to a set of techniques that aim to remove CO_2 directly from the atmosphere by either (1) increasing natural *sinks* for carbon or (2) using chemical engineering to remove the CO_2, with the intent of reducing the atmospheric CO_2 concentration. CDR methods involve the ocean, land and technical systems, including such methods as iron fertilization, large-scale *afforestation* and direct capture of CO_2 from the atmosphere using engineered chemical means. Some CDR methods fall under the category of *geoengineering*, though this may not be the case for others, with the distinction being based on the magnitude, scale and impact of the particular CDR activities. The boundary between CDR and *mitigation* is not clear and there could be some overlap between the two given current definitions (IPCC, 2012b, p. 2). See also *Solar Radiation Management (SRM)*. *{WGI, III}*

Carbon intensity
The amount of emissions of carbon dioxide (CO_2) released per unit of another variable such as Gross Domestic Product (GDP), output energy use or transport. *{WGIII}*

Carbon price
The price for avoided or released carbon dioxide (CO_2) or *CO_2-equivalent emissions*. This may refer to the rate of a *carbon tax*, or the price of emission permits. In many models that are used to assess the economic costs of *mitigation*, carbon prices are used as a proxy to represent the level of effort in mitigation policies. *{WGIII}*

Carbon tax
A levy on the carbon content of fossil fuels. Because virtually all of the carbon in fossil fuels is ultimately emitted as carbon dioxide (CO_2), a carbon tax is equivalent to an emission tax on CO_2 emissions. *{WGIII}*

Climate
Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these

[3] This glossary entry builds from definitions used in the Global Biodiversity Assessment (Heywood, 1995) and the Millennium Ecosystem Assessment (MEA, 2005).

variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the *climate system*. *{WGI, II, III}*

Climate change
Climate change refers to a change in the state of the *climate* that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or *external forcings* such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in *land use*. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of *climate* which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural *climate variability* observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and *climate variability* attributable to natural causes. See also *Detection and Attribution*. *{WGI, II, III}*

Climate extreme (extreme weather or climate event)
See *Extreme weather event*. *{WGI, II}*

Climate feedback
An interaction in which a perturbation in one *climate* quantity causes a change in a second and the change in the second quantity ultimately leads to an additional change in the first. A negative *feedback* is one in which the initial perturbation is weakened by the changes it causes; a positive *feedback* is one in which the initial perturbation is enhanced. In the Fifth Assessment Report, a somewhat narrower definition is often used in which the climate quantity that is perturbed is the global mean surface temperature, which in turn causes changes in the global radiation budget. In either case, the initial perturbation can either be externally forced or arise as part of *internal variability*. *{WGI, II, III}*

Climate finance
There is no agreed definition of climate finance. The term *climate finance* is applied both to the financial resources devoted to addressing *climate change* globally and to financial flows to developing countries to assist them in addressing *climate change*. The literature includes several concepts in these categories, among which the most commonly used include: *{WGIII}*

Incremental costs
The cost of capital of the *incremental investment* and the change of operating and maintenance costs for a *mitigation* or *adaptation* project in comparison to a reference project. It can be calculated as the difference of the net present values of the two projects.

Incremental investment
The extra capital required for the initial investment for a *mitigation* or *adaptation* project in comparison to a reference project.

Total climate finance
All financial flows whose expected effect is to reduce net greenhouse gas (GHG) emissions and/or to enhance *resilience* to the *impacts* of *climate variability* and the projected *climate change*. This covers private and public funds, domestic and international flows and expenditures for *mitigation* and *adaptation* to current *climate variability* as well as future *climate change*.

Total climate finance flowing to developing countries
The amount of the *total climate finance* invested in developing countries that comes from developed countries. This covers private and public funds.

Private climate finance flowing to developing countries
Finance and investment by private actors in/from developed countries for *mitigation* and *adaptation* activities in developing countries.

Public climate finance flowing to developing countries
Finance provided by developed countries' governments and bilateral institutions as well as by multilateral institutions for *mitigation* and *adaptation* activities in developing countries. Most of the funds provided are concessional loans and grants.

Climate model (spectrum or hierarchy)
A numerical representation of the *climate system* based on the physical, chemical and biological properties of its components, their interactions and *feedback* processes and accounting for some of its known properties. The *climate system* can be represented by models of varying complexity; that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical or biological processes are explicitly represented, or the level at which empirical parametrizations are involved. Coupled Atmosphere–Ocean *General Circulation Model*s (AOGCMs) provide a representation of the *climate system* that is near or at the most comprehensive end of the spectrum currently available. There is an evolution towards more complex models with interactive chemistry and biology. Climate models are applied as a research tool to study and simulate the *climate* and for operational purposes, including monthly, seasonal and interannual climate predictions. *{WGI, II, III}*

Climate projection
A climate projection is the simulated response of the *climate system* to a scenario of future emission or concentration of greenhouse gases (GHGs) and aerosols, generally derived using *climate models*. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realized. *{WGI, II, III}*

Climate-resilient pathways
Iterative processes for managing change within complex systems in order to reduce disruptions and enhance opportunities associated with *climate change*. *{WGII}*

Climate response
See *Climate sensitivity*. *{WGI}*

Climate sensitivity
In IPCC reports, *equilibrium climate sensitivity* (units: °C) refers to the equilibrium (steady state) change in the annual global mean surface

temperature following a doubling of the atmospheric *equivalent carbon dioxide (CO_2) concentration*. Owing to computational constraints, the *equilibrium climate sensitivity* in a *climate model* is sometimes estimated by running an atmospheric *general circulation model* coupled to a mixed-layer ocean model, because *equilibrium climate sensitivity* is largely determined by atmospheric processes. Efficient models can be run to equilibrium with a dynamic ocean. The climate sensitivity parameter (units: °C ($W\ m^{-2}$)$^{-1}$) refers to the equilibrium change in the annual global mean surface temperature following a unit change in *radiative forcing*.

The *effective climate sensitivity* (units: °C) is an estimate of the global mean surface temperature response to doubled CO_2 concentration that is evaluated from model output or observations for evolving non-equilibrium conditions. It is a measure of the strengths of the *climate feedbacks* at a particular time and may vary with forcing history and *climate* state and therefore may differ from *equilibrium climate sensitivity*.

The *transient climate response* (units: °C) is the change in the global mean surface temperature, averaged over a 20-year period, centered at the time of atmospheric CO_2 doubling, in a *climate model* simulation in which CO_2 increases at 1%/yr. It is a measure of the strength and rapidity of the surface temperature response to greenhouse gas (GHG) forcing. *{WGI, II, III}*

Climate system
The climate system is the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of *external forcings* such as volcanic eruptions, solar variations and anthropogenic forcings such as the changing composition of the atmosphere and *land-use change*. *{WGI, II, III}*

Climate variability
Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the *climate* on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the *climate system* (*internal variability*), or to variations in natural or anthropogenic *external forcing* (external variability). See also *Climate change*. *{WGI, II, III}*

CO_2-equivalent (CO_2-eq) concentration
The concentration of carbon dioxide (CO_2) that would cause the same *radiative forcing* as a given mixture of CO_2 and other forcing components. Those values may consider only greenhouse gases (GHGs), or a combination of GHGs, aerosols and surface *albedo* change. CO_2-equivalent concentration is a metric for comparing *radiative forcing* of a mix of different forcing components at a particular time but does not imply equivalence of the corresponding climate change responses nor future forcing. There is generally no connection between *CO_2-equivalent emissions* and resulting CO_2-equivalent concentrations. *{WGI, III}*

CO_2-equivalent (CO_2-eq) emission
The amount of carbon dioxide (CO_2) emission that would cause the same integrated *radiative forcing*, over a given time horizon, as an emitted amount of a greenhouse gas (GHG) or a mixture of GHGs. The CO_2-equivalent emission is obtained by multiplying the emission of a GHG by its *Global Warming Potential (GWP)* for the given time horizon (see WGI Chapter 8, Table 8.A.1 and WGIII Annex II.9.1 for *GWP* values of the different GHGs used here). For a mix of GHGs it is obtained by summing the CO_2-equivalent emissions of each gas. CO_2-equivalent emission is a common scale for comparing emissions of different GHGs but does not imply equivalence of the corresponding climate change responses. There is generally no connection between CO_2-equivalent emissions and resulting *CO_2-equivalent concentrations*. *{WGI, III}*

Co-benefits
The positive effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare. Co-benefits are often subject to *uncertainty* and depend on local circumstances and implementation practices, among other factors. Co-benefits are also referred to as *ancillary benefits*. *{WGII, III}*

Confidence
The validity of a finding based on the type, amount, quality and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and on the degree of agreement. In this report, confidence is expressed qualitatively (Mastrandrea et al., 2010). See WGI AR5 Figure 1.11 for the levels of confidence; see WGI AR5 Table 1.2 for the list of *likelihood* qualifiers; see WGII AR5 Box 1-1. See also *Uncertainty*. *{WGI, II, III}*

Cost-effectiveness
A policy is more cost-effective if it achieves a given policy goal at lower cost. *Integrated models* approximate cost-effective solutions, unless they are specifically constrained to behave otherwise. Cost-effective *mitigation scenarios* are those based on a stylized implementation approach in which a single price on carbon dioxide (CO_2) and other greenhouse gases (GHGs) is applied across the globe in every sector of every country and that rises over time in a way that achieves lowest global discounted costs. *{WGIII}*

Decarbonization
The process by which countries or other entities aim to achieve a low-carbon economy, or by which individuals aim to reduce their consumption of carbon. *{WGII, III}*

Deforestation
Conversion of *forest* to non-*forest*. For a discussion of the term *forest* and related terms such as *afforestation*, *reforestation* and *deforestation*, see the IPCC Special Report on Land Use, Land-Use Change, and Forestry (IPCC, 2000b). See also information provided by the United Nations Framework Convention on Climate Change (UNFCCC, 2013) and the report on Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types (IPCC, 2003). *{WGI, II}*

Detection and attribution
Detection of change is defined as the process of demonstrating that *climate* or a system affected by *climate* has changed in some defined statistical sense, without providing a reason for that change. An identified change is detected in observations if its *likelihood* of occurrence by chance due to *internal variability* alone is determined to be small,

for example, <10%. *Attribution* is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with an assignment of statistical confidence (Hegerl et al., 2010). *{WGI, II}*

Detection of impacts of climate change
For a natural, human or managed system, identification of a change from a specified *baseline*. The *baseline* characterizes behavior in the absence of *climate change* and may be stationary or non-stationary (e.g., due to *land-use change*). *{WGII}*

Disaster
Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery. *{WGII}*

Discounting
A mathematical operation making monetary (or other) amounts received or expended at different times (years) comparable across time. The discounter uses a fixed or possibly time-varying discount rate (>0) from year to year that makes future value worth less today. *{WGII, III}*

Drought
A period of abnormally dry weather long enough to cause a serious hydrological imbalance. Drought is a relative term; therefore any discussion in terms of precipitation deficit must refer to the particular precipitation-related activity that is under discussion. For example, shortage of precipitation during the growing season impinges on crop production or *ecosystem* function in general (due to soil moisture drought, also termed agricultural drought) and during the runoff and percolation season primarily affects water supplies (hydrological drought). Storage changes in soil moisture and groundwater are also affected by increases in actual evapotranspiration in addition to reductions in precipitation. A period with an abnormal precipitation deficit is defined as a meteorological drought. A megadrought is a very lengthy and pervasive drought, lasting much longer than normal, usually a decade or more. For the corresponding indices, see WGI AR5 Box 2.4. *{WGI, II}*

Early warning system
The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a *hazard* to prepare to act promptly and appropriately to reduce the possibility of harm or loss[4]. *{WGII}*

Earth System Model (ESM)
A coupled atmosphere–ocean *general circulation model* in which a representation of the *carbon cycle* is included, allowing for interactive calculation of atmospheric CO_2 or compatible emissions. Additional components (e.g., atmospheric chemistry, ice sheets, dynamic vegetation, nitrogen cycle, but also urban or crop models) may be included. See also *Climate model*. *{WGI, II}*

Ecosystem
An ecosystem is a functional unit consisting of living organisms, their non-living environment and the interactions within and between them. The components included in a given ecosystem and its spatial boundaries depend on the purpose for which the ecosystem is defined: in some cases they are relatively sharp, while in others they are diffuse. Ecosystem boundaries can change over time. Ecosystems are nested within other ecosystems and their scale can range from very small to the entire biosphere. In the current era, most ecosystems either contain people as key organisms, or are influenced by the effects of human activities in their environment. *{WGI, II, III}*

Ecosystem services
Ecological processes or functions having monetary or non-monetary value to individuals or society at large. These are frequently classified as (1) supporting services such as productivity or *biodiversity* maintenance, (2) provisioning services such as food, fiber or fish, (3) regulating services such as *climate* regulation or carbon *sequestration* and (4) cultural services such as tourism or spiritual and aesthetic appreciation. *{WGII, III}*

El Niño-Southern Oscillation (ENSO)
The term *El Niño* was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. It has since become identified with a basin-wide warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the *Southern Oscillation*. This coupled atmosphere–ocean phenomenon, with preferred time scales of two to about seven years, is known as the *El Niño-Southern Oscillation (ENSO).* It is often measured by the surface pressure anomaly difference between Tahiti and Darwin or the sea surface temperatures in the central and eastern equatorial Pacific. During an ENSO event, the prevailing trade winds weaken, reducing upwelling and altering ocean currents such that the sea surface temperatures warm, further weakening the trade winds. This event has a great impact on the wind, sea surface temperature and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world, through global teleconnections. The cold phase of ENSO is called *La Niña*. For the corresponding indices, see WGI AR5 Box 2.5. *{WGI, II}*

Emission scenario
A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases (GHGs), aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change, energy and *land use*) and their key relationships. Concentration scenarios, derived from emission scenarios, are used as input to a *climate model* to compute *climate projections*. In IPCC (1992) a set of emission scenarios was presented which were used as a basis for the *climate projections* in IPCC (1996). These emission scenarios are referred to as the IS92 scenarios. In the IPCC Special Report on Emissions Scenarios (IPCC, 2000a) emission scenarios, the so-called *SRES scenarios*, were published, some of

[4] This glossary entry builds from the definitions used in UNISDR (2009) and IPCC (2012a).

which were used, among others, as a basis for the *climate projections* presented in Chapters 9 to 11 of IPCC WGI TAR (IPCC, 2001a) and Chapters 10 and 11 of IPCC WGI AR4 (IPCC, 2007) as well as in the IPCC WGI AR5 (IPCC, 2013b). New emission scenarios for *climate change*, the four *Representative Concentration Pathways*, were developed for, but independently of, the present IPCC assessment. See also *Baseline/reference*, *Mitigation scenario* and *Transformation pathway*. *{WGI, II, III}*

Energy access
Access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses (AGECC, 2010). *{WGIII}*

Energy intensity
The ratio of energy use to economic or physical output. *{WGIII}*

Energy security
The goal of a given country, or the global community as a whole, to maintain an adequate, stable and predictable energy supply. Measures encompass safeguarding the sufficiency of energy resources to meet national energy demand at competitive and stable prices and the *resilience* of the energy supply; enabling development and deployment of technologies; building sufficient infrastructure to generate, store and transmit energy supplies and ensuring enforceable contracts of delivery. *{WGIII}*

Ensemble
A collection of model simulations characterizing a *climate* prediction or *projection*. Differences in initial conditions and model formulation result in different evolutions of the modeled system and may give information on uncertainty associated with model error and error in initial conditions in the case of *climate* forecasts and on *uncertainty* associated with model error and with internally generated *climate variability* in the case of *climate projections*. *{WGI, II}*

Equilibrium climate sensitivity
See *Climate sensitivity*. *{WGI}*

Eutrophication
Over-enrichment of water by nutrients such as nitrogen and phosphorus. It is one of the leading causes of water quality impairment. The two most acute symptoms of eutrophication are hypoxia (or oxygen depletion) and harmful algal blooms. *{WGII}*

Exposure
The presence of people, livelihoods, species or *ecosystems*, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected. *{WGII}*

External forcing
External forcing refers to a forcing agent outside the *climate system* causing a change in the *climate system*. Volcanic eruptions, solar variations and anthropogenic changes in the composition of the atmosphere and *land-use change* are external forcings. Orbital forcing is also an external forcing as the insolation changes with orbital parameters eccentricity, tilt and precession of the equinox. *{WGI, II}*

Extreme weather event
An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an *extreme climate event*, especially if it yields an average or total that is itself extreme (e.g., *drought* or heavy rainfall over a season). *{WGI, II}*

Feedback
See *Climate feedback*. *{WGI, II}*

Flood
The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods and glacial lake outburst floods. *{WGII}*

Food security
A state that prevails when people have secure access to sufficient amounts of safe and nutritious food for normal growth, development and an active and healthy life. *{WGII, III}*

Forest
A vegetation type dominated by trees. Many definitions of the term *forest* are in use throughout the world, reflecting wide differences in biogeophysical conditions, social structure and economics. For a discussion of the term *forest* and related terms such as *afforestation*, *reforestation* and *deforestation*, see the IPCC Special Report on Land Use, Land-Use Change, and Forestry (IPCC, 2000b). See also information provided by the United Nations Framework Convention on Climate Change (UNFCCC, 2013) and the Report on Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types (IPCC, 2003). *{WGI, III}*

Fuel poverty
A condition in which a household is unable to guarantee a certain level of consumption of domestic energy services (especially heating) or suffers disproportionate expenditure burdens to meet these needs. *{WGIII}*

Geoengineering
Geoengineering refers to a broad set of methods and technologies that aim to deliberately alter the *climate system* in order to alleviate the *impacts* of *climate change*. Most, but not all, methods seek to either (1) reduce the amount of absorbed solar energy in the *climate system* (*Solar Radiation Management*) or (2) increase net carbon *sinks* from the atmosphere at a scale sufficiently large to alter *climate* (*Carbon Dioxide Removal*). Scale and intent are of central importance. Two key characteristics of geoengineering methods of particular concern are that they use or affect the *climate system* (e.g., atmosphere, land or ocean) globally or regionally and/or could have substantive unintended effects that cross national boundaries. Geoengineering is different from weather modification and ecological engineering, but the boundary can be fuzzy (IPCC, 2012b, p. 2). *{WGI, II, III}*

Global climate model (also referred to as general circulation model, both abbreviated as GCM)
See *Climate model*. *{WGI, II}*

Global Temperature change Potential (GTP)
An index measuring the change in global mean surface temperature at a chosen point in time following an emission of a unit mass of a given substance, relative to that of the reference substance, carbon dioxide (CO_2). The Global Temperature change Potential (GTP) thus represents the combined effect of the differing times these substances remain in the atmosphere, their effectiveness in causing *radiative forcing* and the response of the *climate system*. The GTP has been defined in two different ways:

- Fixed GTP: based on a fixed time horizon in the future (such as GTP_{100} for a time horizon of 100 years)
- Dynamic GTP: based on a target year (such as the year when global mean temperature is expected to reach a target level). In the dynamic GTP, the time horizon reduces over time as the target year is approached and hence the GTP value changes for emissions occurring further in the future. *{WGI Chapter 8}*

Global warming
Global warming refers to the gradual increase, observed or projected, in global surface temperature, as one of the consequences of *radiative forcing* caused by anthropogenic emissions. *{WGIII}*

Global Warming Potential (GWP)
An index measuring the *radiative forcing* following an emission of a unit mass of a given substance, accumulated over a chosen time horizon, relative to that of the reference substance, carbon dioxide (CO_2). The GWP thus represents the combined effect of the differing times these substances remain in the atmosphere and their effectiveness in causing *radiative forcing*. *(WGI, III}*

Hazard
The potential occurrence of a natural or human-induced physical event or trend or physical *impact* that may cause loss of life, injury, or other health *impacts*, as well as damage and loss to property, infrastructure, livelihoods, service provision, *ecosystems* and environmental resources. In this report, the term *hazard* usually refers to *climate*-related physical events or trends or their physical *impacts*. *{WGII}*

Heat wave
A period of abnormally and uncomfortably hot weather. *{WGI, II}*

Hydrological cycle
The cycle in which water evaporates from the oceans and the land surface, is carried over the Earth in atmospheric circulation as water vapour, condenses to form clouds, precipitates over ocean and land as rain or snow, which on land can be intercepted by trees and vegetation, provides runoff on the land surface, infiltrates into soils, recharges groundwater, discharges into streams and ultimately flows out into the oceans, from which it will eventually evaporate again. The various systems involved in the hydrological cycle are usually referred to as hydrological systems. *{WGI, II}*

Impacts (consequences, outcomes)
Effects on natural and human systems. In this report, the term *impacts* is used primarily to refer to the effects on natural and human systems of *extreme weather and climate events* and of *climate change*. Impacts generally refer to effects on lives, livelihoods, health, *ecosystems*, economies, societies, cultures, services and infrastructure due to the interaction of *climate changes* or hazardous climate events occurring within a specific time period and the *vulnerability* of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of *climate change* on geophysical systems, including *floods*, *droughts* and sea level rise, are a subset of impacts called physical impacts. *{WGII}*

Indirect emissions
Emissions that are a consequence of the activities within well-defined boundaries of, for instance, a region, an economic sector, a company or process, but which occur outside the specified boundaries. For example, emissions are described as indirect if they relate to the use of heat but physically arise outside the boundaries of the heat user, or to electricity production but physically arise outside of the boundaries of the power supply sector. *{WGIII}*

Industrial Revolution
A period of rapid industrial growth with far-reaching social and economic consequences, beginning in Britain during the second half of the 18th century and spreading to Europe and later to other countries including the United States. The invention of the steam engine was an important trigger of this development. The industrial revolution marks the beginning of a strong increase in the use of fossil fuels and emission of, in particular, fossil carbon dioxide (CO_2). In this report the terms *pre-industrial* and *industrial* refer, somewhat arbitrarily, to the periods before and after 1750, respectively. *{WGI, II, III}*

Integrated assessment
A method of analysis that combines results and models from the physical, biological, economic and social sciences and the interactions among these components in a consistent framework to evaluate the status and the consequences of environmental change and the policy responses to it. See also *Integrated models*. *{WGII, III}*

Integrated Coastal Zone Management (ICZM)
An integrated approach for sustainably managing coastal areas, taking into account all coastal habitats and uses. *{WGII}*

Integrated models
Integrated models explore the interactions between multiple sectors of the economy or components of particular systems, such as the energy system. In the context of *transformation pathways*, they refer to models that, at a minimum, include full and disaggregated representations of the energy system and its linkage to the overall economy that will allow for consideration of interactions among different elements of that system. Integrated models may also include representations of the full economy, *land use and land-use change (LUC)* and the *climate system*. See also *Integrated assessment*. *{WGIII}*

Internal variability
See *Climate variability*. *{WGI}*

Irreversibility
A perturbed state of a dynamical system is defined as irreversible on a given timescale, if the recovery timescale from this state due to natural processes is substantially longer than the time it takes for the system to reach this perturbed state. In the context of this report, the time scale of interest is centennial to millennial. See also *Tipping point*. *{WGI}*

Land use and land-use change
Land use refers to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term *land use* is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction and conservation). In urban settlements it is related to land uses within cities and their hinterlands. Urban land use has implications on city management, structure and form and thus on energy demand, greenhouse gas (GHG) emissions and mobility, among other aspects. *{WGI, II, III}*

Land-use change (LUC)
Land-use change refers to a change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land-use change may have an impact on the surface *albedo*, evapotranspiration, sources and *sinks* of greenhouse gases (GHGs), or other properties of the *climate system* and may thus give rise to *radiative forcing* and/or other *impacts* on *climate*, locally or globally. See also the IPCC Special Report on Land Use, Land-Use Change, and Forestry (IPCC, 2000b).

Indirect land-use change (iLUC)
Indirect land-use change refers to shifts in land use induced by a change in the production level of an agricultural product elsewhere, often mediated by markets or driven by policies. For example, if agricultural land is diverted to fuel production, *forest* clearance may occur elsewhere to replace the former agricultural production. See also *Agriculture, Forestry and Other Land Use (AFOLU)*, *Afforestation*, *Deforestation* and *Reforestation*.

Leakage
Phenomena whereby the reduction in emissions (relative to a *baseline*) in a jurisdiction/sector associated with the implementation of *mitigation* policy is offset to some degree by an increase outside the jurisdiction/sector through induced changes in consumption, production, prices, *land use* and/or trade across the jurisdictions/sectors. Leakage can occur at a number of levels, be it a project, state, province, nation or world region.

In the context of *Carbon Dioxide Capture and Storage (CCS)*, *CO_2 leakage* refers to the escape of injected carbon dioxide (CO_2) from the storage location and eventual release to the atmosphere. In the context of other substances, the term is used more generically, such as for *methane (CH_4) leakage* (e.g., from fossil fuel extraction activities) and *hydrofluorocarbon (HFC) leakage* (e.g., from refrigeration and air-conditioning systems). *{WGIII}*

Likelihood
The chance of a specific outcome occurring, where this might be estimated probabilistically. Likelihood is expressed in this report using a standard terminology (Mastrandrea et al., 2010), defined in WGI AR5 Table 1.2 and WGII AR5 Box 1-1. See also *Confidence* and *Uncertainty*. *{WGI, II, III}*

Lock-in
Lock-in occurs when a market is stuck with a standard even though participants would be better off with an alternative. In this report, lock-in is used more broadly as path dependence, which is the generic situation where decisions, events or outcomes at one point in time constrain *adaptation*, *mitigation* or other actions or options at a later point in time. *{WGII, III}*

Low regrets policy
A policy that would generate net social and/or economic benefits under current *climate* and a range of future *climate change* scenarios. *{WGII}*

Marine-based ice sheet
An ice sheet containing a substantial region that rests on a bed lying below sea level and whose perimeter is in contact with the ocean. The best known example is the West Antarctic ice sheet. *{WGI}*

Meridional Overturning Circulation (MOC)
Meridional (north–south) overturning circulation in the ocean quantified by zonal (east–west) sums of mass transports in depth or density layers. In the North Atlantic, away from the subpolar regions, the MOC (which is in principle an observable quantity) is often identified with the thermohaline circulation (THC), which is a conceptual and incomplete interpretation. It must be borne in mind that the MOC is also driven by wind and can also include shallower overturning cells such as occur in the upper ocean in the tropics and subtropics, in which warm (light) waters moving poleward are transformed to slightly denser waters and subducted equatorward at deeper levels. *{WGI, II}*

Mitigation (of climate change)
A human intervention to reduce the sources or enhance the *sinks* of greenhouse gases (GHGs). This report also assesses human interventions to reduce the sources of other substances which may contribute directly or indirectly to limiting *climate change*, including, for example, the reduction of particulate matter emissions that can directly alter the radiation balance (e.g., black carbon) or measures that control emissions of carbon monoxide, nitrogen oxides, Volatile Organic Compounds and other pollutants that can alter the concentration of tropospheric ozone which has an indirect effect on the *climate*. *{WGI, II, III}*

Mitigation scenario
A plausible description of the future that describes how the (studied) system responds to the implementation of *mitigation* policies and measures. See also *Baseline/reference*, *Emission scenario*, *Representative Concentration Pathways (RCPs)*, *SRES scenarios* and *Transformation pathway*. *{WGIII}*

Net negative emissions
A situation of net negative emissions is achieved when, as result of human activities, more greenhouse gases (GHGs) are sequestered or stored than are released into the atmosphere. *{SYR Box 2.2, footnote 29}*

Ocean acidification
Ocean acidification refers to a reduction in the *pH* of the ocean over an extended period, typically decades or longer, which is caused primarily

by uptake of carbon dioxide (CO_2) from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean. *Anthropogenic ocean acidification* refers to the component of *pH* reduction that is caused by human activity (IPCC, 2011, p. 37). *{WGI, II}*

Overshoot pathways
Emissions, concentration or temperature pathways in which the metric of interest temporarily exceeds, or *overshoots* the long-term goal. *{WGIII}*

Oxygen Minimum Zone (OMZ)
The midwater layer (200–1000 m) in the open ocean in which oxygen saturation is the lowest in the ocean. The degree of oxygen depletion depends on the largely bacterial consumption of organic matter and the distribution of the OMZs is influenced by large-scale ocean circulation. In coastal oceans, OMZs extend to the shelves and may also affect benthic *ecosystems*. *{WGII}*

Permafrost
Ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years. *{WGI, II}*

pH
pH is a dimensionless measure of the acidity of water (or any solution) given by its concentration of hydrogen ions (H^+). pH is measured on a logarithmic scale where $pH = -\log_{10}(H^+)$. Thus, a pH decrease of 1 unit corresponds to a 10-fold increase in the concentration of H^+, or acidity. *{WGI}*

Poverty
Poverty is a complex concept with several definitions stemming from different schools of thought. It can refer to material circumstances (such as need, pattern of deprivation or limited resources), economic conditions (such as standard of living, inequality or economic position) and/or social relationships (such as social class, dependency, exclusion, lack of basic security or lack of entitlement). *{WGII}*

Pre-industrial
See *Industrial Revolution*. *{WGI, II, III}*

Private costs
Private costs are carried by individuals, companies or other private entities that undertake an action, whereas *social costs* include additionally the external costs on the environment and on society as a whole. Quantitative estimates of both private and social costs may be incomplete, because of difficulties in measuring all relevant effects. *{WGIII}*

Projection
A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realized. See also *Climate projection*. *{WGI, II}*

Radiative forcing
The strength of drivers is quantified as Radiative Forcing (RF) in units watts per square meter (W/m^2) as in previous IPCC assessments. RF is the change in energy flux caused by a driver and is calculated at the tropopause or at the top of the atmosphere. *{WGI}*

Reasons For Concern (RFCs)
Elements of a classification framework, first developed in the IPCC Third Assessment Report (IPCC, 2001b), which aims to facilitate judgments about what level of *climate change* may be *dangerous* (in the language of Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC)) by aggregating *impacts*, *risks* and *vulnerabilities*. *{WGII}*

Reducing Emissions from Deforestation and Forest Degradation (REDD)
An effort to create financial value for the carbon stored in *forests*, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to *sustainable development* (SD). It is therefore a mechanism for *mitigation* that results from avoiding *deforestation*. REDD+ goes beyond *reforestation* and *forest* degradation and includes the role of conservation, sustainable management of *forests* and enhancement of *forest* carbon stocks. The concept was first introduced in 2005 in the 11th Session of the Conference of the Parties (COP) in Montreal and later given greater recognition in the 13th Session of the COP in 2007 at Bali and inclusion in the Bali Action Plan which called for 'policy approaches and positive incentives on issues relating to reducing emissions from *deforestation* and *forest* degradation in developing countries (REDD) and the role of conservation, sustainable management of *forests* and enhancement of *forest* carbon stock in developing countries'. Since then, support for REDD has increased and has slowly become a framework for action supported by a number of countries. *{WGIII}*

Reforestation
Planting of *forests* on lands that have previously contained *forests* but that have been converted to some other use. For a discussion of the term *forest* and related terms such as *afforestation*, *reforestation* and *deforestation*, see the IPCC Special Report on Land Use, Land-Use Change, and Forestry (IPCC, 2000b). See also information provided by the United Nations Framework Convention on Climate Change (UNFCCC, 2013). See also the Report on Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types (IPCC, 2003). *{WGI, II, III}*

Representative Concentration Pathways (RCPs)
Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as *land use*/land cover (Moss et al., 2008). The word representative signifies that each RCP provides only one of many possible scenarios that would lead to the specific *radiative forcing* characteristics. The term *pathway* emphasizes that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome (Moss et al., 2010).

RCPs usually refer to the portion of the concentration pathway extending up to 2100, for which Integrated Assessment Models produced corresponding *emission scenarios*. Extended Concentration Pathways (ECPs) describe extensions of the RCPs from 2100 to 2500 that were

calculated using simple rules generated by stakeholder consultations and do not represent fully consistent scenarios.

Four RCPs produced from *Integrated Assessment Models* were selected from the published literature and are used in the present IPCC Assessment as a basis for the *climate* predictions and *projections* presented in WGI AR5 Chapters 11 to 14 (IPCC, 2013b):

RCP2.6
One pathway where *radiative forcing* peaks at approximately 3 W/m^2 before 2100 and then declines (the corresponding ECP assuming constant emissions after 2100).

RCP4.5 and RCP6.0
Two intermediate stabilization pathways in which *radiative forcing* is stabilized at approximately 4.5 W/m^2 and 6.0 W/m^2 after 2100 (the corresponding ECPs assuming constant concentrations after 2150).

RCP8.5
One high pathway for which *radiative forcing* reaches >8.5 W/m^2 by 2100 and continues to rise for some amount of time (the corresponding ECP assuming constant emissions after 2100 and constant concentrations after 2250).

For further description of future scenarios, see WGI AR5 Box 1.1. See also van Vuuren et al., 2011. *{WGI, II, III}*

Resilience
The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for *adaptation*, learning and *transformation*[5]. *{WGII, III}*

Risk
The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or *likelihood* of occurrence of hazardous events or trends multiplied by the *impacts* if these events or trends occur. In this report, the term *risk* is often used to refer to the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, *ecosystems* and species, economic, social and cultural assets, services (including environmental services) and infrastructure. *{WGII, III}*

Risk management
The plans, actions or policies to reduce the *likelihood* and/or consequences of *risks* or to respond to consequences. *{WGII}*

Sequestration
The uptake (i.e., the addition of a substance of concern to a reservoir) of carbon containing substances, in particular carbon dioxide (CO_2), in terrestrial or marine reservoirs. Biological sequestration includes direct removal of CO_2 from the atmosphere through *land-use change (LUC)*, *afforestation*, *reforestation*, revegetation, carbon storage in landfills and practices that enhance soil carbon in agriculture (cropland management, grazing land management). In parts of the literature, but not in this report, (carbon) sequestration is used to refer to *Carbon Dioxide Capture and Storage (CCS)*. *{WGIII}*

Sink
Any process, activity or mechanism that removes a greenhouse gas (GHG), an aerosol or a precursor of a GHG or aerosol from the atmosphere. *{WGI, II, III}*

Social cost of carbon
The net present value of climate damages (with harmful damages expressed as a positive number) from one more tonne of carbon in the form of carbon dioxide (CO_2), conditional on a global emissions trajectory over time. *{WGII, III}*

Social costs
See *Private costs*. *{WGIII}*

Solar Radiation Management (SRM)
Solar Radiation Management refers to the intentional modification of the Earth's shortwave radiative budget with the aim to reduce *climate change* according to a given metric (e.g., surface temperature, precipitation, regional *impacts*, etc.). Artificial injection of stratospheric aerosols and cloud brightening are two examples of SRM techniques. Methods to modify some fast-responding elements of the long wave radiative budget (such as cirrus clouds), although not strictly speaking SRM, can be related to SRM. SRM techniques do not fall within the usual definitions of *mitigation* and *adaptation* (IPCC, 2012b, p. 2). See also *Carbon Dioxide Removal (CDR)* and *Geoengineering*. *{WGI, III}*

SRES scenarios
SRES scenarios are *emission scenarios* developed by IPCC (2000a) and used, among others, as a basis for some of the *climate projections* shown in Chapters 9 to 11 of IPCC WGI TAR (IPCC, 2001a), Chapters 10 and 11 of IPCC WGI AR4 (IPCC, 2007), as well as in the IPCC WGI AR5 (IPCC, 2013b). *{WGI, II, III}*

Storm surge
The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place. *{WGI, II}*

Structural change
Changes, for example, in the relative share of gross domestic product (GDP) produced by the industrial, agricultural, or services sectors of an economy, or more generally, systems *transformations* whereby some components are either replaced or potentially substituted by other components. *{WGIII}*

Sustainability
A dynamic process that guarantees the persistence of natural and human systems in an equitable manner. *{WGII, III}*

[5] This definition builds from the definition used in Arctic Council (2013).

Sustainable development
Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). *{WGII, III}*

Thermal expansion
In connection with sea level, this refers to the increase in volume (and decrease in density) that results from warming water. A warming of the ocean leads to an expansion of the ocean volume and hence an increase in sea level. *{WGI, II}*

Tipping point
A level of change in system properties beyond which a system reorganizes, often abruptly, and does not return to the initial state even if the drivers of the change are abated. For the *climate system*, it refers to a critical threshold when global or regional *climate changes* from one stable state to another stable state. The tipping point event may be irreversible. See also *Irreversibility*. *{WGI, II, III}*

Transformation
A change in the fundamental attributes of natural and human systems. *{WGII}*

Transformation pathway
The trajectory taken over time to meet different goals for greenhouse gas (GHG) emissions, atmospheric concentrations, or global mean surface temperature change that implies a set of economic, technological and behavioural changes. This can encompass changes in the way energy and infrastructure are used and produced, natural resources are managed and institutions are set up and in the pace and direction of technological change (TC). See also *Baseline/reference*, *Emission scenario*, *Mitigation scenario, Representative Concentration Pathways (RCPs)* and *SRES scenarios*. *{WGIII}*

Transient Climate Response to Cumulative CO_2 Emissions (TCRE)
The transient global average surface temperature change per unit cumulated CO_2 emissions, usually 1000 PgC. TCRE combines both information on the airborne fraction of cumulated CO_2 emissions (the fraction of the total CO_2 emitted that remains in the atmosphere) and on the transient climate response (TCR). *{WGI}*

Uncertainty
A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts) (see Moss and Schneider, 2000; Manning et al., 2004; Mastrandrea et al., 2010). See also *Confidence* and *Likelihood*. *{WGI, II, III}*

Vulnerability
The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. *{WGII}*

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ANNEX III

Acronyms, Chemical Symbols and Scientific Units

µatm	Microatmosphere
AFOLU	Agriculture, Forestry and Other Land Use
AMOC	Atlantic Meridional Overturning Circulation
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
BAT	Best Available Technique
BAU	Business As Usual
BECCS	Bioenergy with Carbon Dioxide Capture and Storage
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CDR	Carbon Dioxide Removal
CF_4	Perfluoromethane
CH_4	Methane
CHP	Combined Heat and Power
CMIP5	Coupled Model Intercomparison Project Phase 5
CO_2	Carbon Dioxide
CO_2-eq	Carbon Dioxide Equivalent
CSP	Concentrating Solar Power
DC	Developing Country
ECS	Equilibrium Climate Sensitivity
EDGAR	Emission Database for Global Atmospheric Research
EJ	Exajoule
EMIC	Earth System Model of Intermediate Complexity
ENSO	El Niño-Southern Oscillation
ES	Executive Summary
ESM	Earth System Model
ETS	Emissions Trading System
F-gases	Fluorinated gases
FAQ	Frequently Asked Question
FAR	First Assessment Report
FIT	Feed-in Tariff
FOLU	Forestry and Other Land Use
GCM	Global Climate Model
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GMI	Global Methane Initiative
Gt	Gigatonnes
GTP	Global Temperature change Potential
GWP	Global Warming Potential
H_2	Hydrogen
HadCRUT4	Hadley Centre Climatic Research Unit Gridded Surface Temperature Data Set 4
HDV	Heavy-Duty Vehicles
HFC	Hydrofluorocarbon
HFC-152a	Hydrofluorocarbon-152a, Difluoroethane
IAM	Integrated Assessment Model
ICAO	International Civil Aviation Organization
IMO	International Maritime Organization
IO	International Organization
LDV	Light-Duty Vehicles
LULUCF	Land Use, Land-Use Change and Forestry
MAGICC	Model for the Assessment of Greenhouse Gas Induced Climate Change
MEF	Major Economies Forum
MRV	Monitoring, Reporting and Verification
N_2O	Nitrous Oxide
NAMA	Nationally Appropriate Mitigation Action
NAP	National Adaptation Plan
NAPA	National Adaptation Programmes of Action

NGO	Non-Governmental Organization
O_2	Oxygen
OA	Ocean Acidification
OECD	Organisation for Economic Co-operation and Development
PFC	Perfluorocarbon
ppb	parts per billion
ppm	parts per million
PV	Photovoltaic
R&D	Research and Development
RCP	Representative Concentration Pathway
RE	Renewable Energy
REDD	Reducing Emissions from Deforestation and Forest Degradation
REEEP	Renewable Energy and Energy Efficiency Partnership
RES	Renewable Energy System
RFC	Reason For Concern
RPS	Renewable Portfolio Standard
SAR	Second Assessment Report
SM	Supplementary Material
SO_2	Sulfur Dioxide
SPM	Summary for Policymakers
SRES	Special Report on Emissions Scenarios
SREX	Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
SRM	Solar Radiation Management
SRREN	Special Report on Renewable Energy Sources and Climate Change Mitigation
SYR	Synthesis Report
TCR	Transient Climate Response
TCRE	Transient Climate Response to Cumulative CO_2 Emissions
TFE	Thematic Focus Element
TS	Technical Summary
UHI	Urban Heat Island
UNFCCC	United Nations Framework Convention on Climate Change
W	Watt
WG	Working Group
WMGHG	Well-Mixed Greenhouse Gas

ANNEX IV

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ANNEX VI

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- Adaptation and mitigation

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REPORTS - ASSESSMENT REPORTS

IPCC Fourth Assessment Report (AR4)

Climate Change 2007: The Physical Science Basis



Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change
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LETTERS
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Committed terrestrial ecosystem changes due to climate change

Chris Jones*, Jason Lowe, Spencer Liddicoat and Richard Betts

Targets for stabilizing climate change are often based on considerations of the impacts of different levels of global warming, usually assessing the time of reaching a particular level of warming. However, some aspects of the Earth system, such as global mean temperatures[1] and sea level rise due to thermal expansion[2] or the melting of large ice sheets[3], continue to respond long after the stabilization of radiative forcing. Here we use a coupled climate–vegetation model to show that in turn the terrestrial biosphere shows significant inertia in its response to climate change. We demonstrate that the global terrestrial biosphere can continue to change for decades after climate stabilization. We suggest that ecosystems can be committed to long-term change long before any response is observable: for example, we find that the risk of significant loss of forest cover in Amazonia rises rapidly for a global mean temperature rise above 2 °C. We conclude that such committed ecosystem changes must be considered in the definition of dangerous climate change, and subsequent policy development to avoid it.

Future climate change and the carbon cycle are tightly coupled[4]. Many studies (such as refs 5, 6) have now shown positive feedbacks that amplify climate change, reduce the natural uptake of carbon and influence global emissions pathways to stabilization[7,8]. On the timescale of 1 or 2 centuries, the contribution to this feedback is likely to be greater from the terrestrial biosphere than from the ocean carbon cycle[6]. Rising temperature enhances soil decomposition and together with reductions in rainfall, may also reduce plant productivity in large regions. Changes in climate may also alter the important biomes—especially tropical and boreal forests[9]. Climate impacts are often summarized for policy makers as a table of impact magnitude against global mean warming (for example, the Stern Review[10]). However, a significant limitation is that some of the impacts are taken from model simulations at the instant the temperature is reached, and fail to account for subsequent impacts as slowly responding parts of the system fully respond to the given change.

The increase in global mean temperature due to increasing greenhouse gas concentrations lags behind the radiative forcing that causes it because of the thermal inertia of the system[1]. For present-day climate, this committed rise has been predicted to be between 0.25 and 0.5 °C (ref. 11). Other components of the climate system also show committed change. Sea level rise from thermal expansion seems likely to increase for several centuries to millennia following stabilization of radiative forcing[2,11], and the contribution to sea level rise from melting of the Greenland ice sheet is also likely to continue long after radiative forcing is stabilized[3,12]. Terrestrial ecosystems might also show committed change behaviour following stabilization of forcing because changes in both vegetation cover and carbon storage are likely to lag behind that of temperature and rainfall. Hence, we introduce the new concept of committed ecosystem change and examine the extent to which biomes may be committed to significant changes in response to climate forcing before they can be observed.

The Intergovernmental Panel on Climate Change Second Assessment Report noted that climate change is expected at a rapid rate compared with forest ecosystem timescales[13] but neither subsequent IPCC Assessment reports nor the published literature have discussed the implications of this statement in terms of committed changes to important ecosystems. We present examples from the Amazon and boreal forests to show how important such committed changes may be.

The Met Office Hadley Centre climate carbon cycle model, HadCM3LC, is one of only a few coupled general circulation model (GCM)–dynamic vegetation models. Previous analysis[14,15] has examined the large-scale loss of Amazon forest simulated by this model in response to transient scenarios of climate change. Other studies that examined tropical ecosystem response under climate change simulations from a range of climate models[16,17] and using a range of vegetation models (some with a greater degree of species diversity)[9] also showed reductions in tropical forest cover, especially in Amazonia. Observational studies have also shown the vulnerability of the Amazon forest to drought[18]. Although HadCM3LC produces greater regional climate change and die-back than some offline model studies, other models do project changes that, although less extreme, are qualitatively similar[9] (see Supplementary Information). All of these studies, however, have focused on the period of changing forcing rather than behaviour subsequent to stabilization. We study here the long-term committed changes (see the Methods section and Supplementary Information).

Figure 1 shows a comparison of the realized and committed vegetation cover in a region of the Amazon forest (we consider the region of land within the area defined by 40° W–70° W and 15° S–5° N, as shown in Fig. 2). Figure 1a shows fractional forest cover in this region as it changes in time. Figure 1b shows the same data but shown as degree of die-back plotted against global mean temperature above pre-industrial. It is clear that the forest cover in the equilibrium simulations (dashed line) is significantly lower than the dynamic state. This indicates that at any time the forest is showing only a portion of the level of die-back it will eventually reach. For example, by 2050 when die-back begins to be observed in the transient simulation, the forest is already committed to eventually losing 50% of its area even without further increases in forcing (Fig. 2). This is roughly the same loss as seen in the transient simulations, with increasing forcing, by 2100 (Fig. 1). By 2100, even though only a third of tree cover has gone, the forest is committed to almost complete loss in this region. The solid line can be considered as the impact when a particular level of warming is first reached. The dashed line is the eventual impact after warming is sustained at the stabilization temperature for a long period of time.

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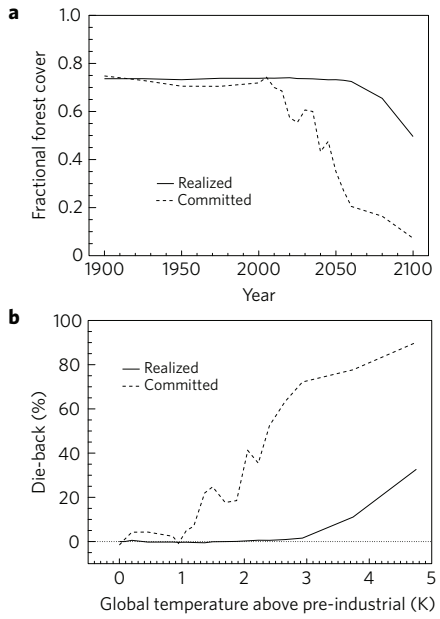


Figure 1 | Dynamic and equilibrium Amazon forest extent throughout the simulations. a, Fractional tree cover (represented as fractional coverage of broadleaf trees in the region 40°–70° W, 15° S–5° N) as it evolves dynamically through the SRES A2 simulation and the committed state corresponding to each year. **b**, The same information plotted as the percentage of complete die-back as a function of global mean temperature rise above pre-industrial (defined as 0 for the original, pre-industrial forest cover, and 100 for complete loss of tree cover in this region).

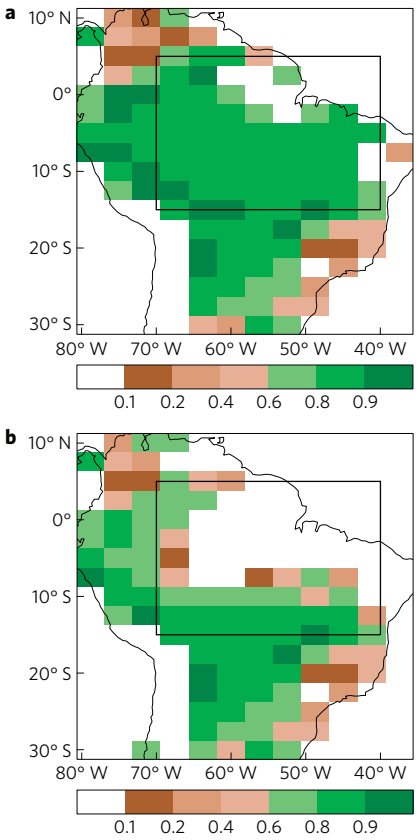


Figure 2 | Geographical distribution of Amazon forest tree cover at 2050. a,**b**, Realized (**a**) and committed (**b**) states represented as fractional coverage of broadleaf trees simulated by the model. The black rectangle shows the region used for calculating mean forest cover.

There seems to be a temperature below which the equilibrium state of the forest is approximately constant, but above which the equilibrium forest cover declines steadily with changing climate. This point could be seen as a threshold beyond which some degree of loss of Amazon forest is inevitable. Beyond this point there is no sudden transition from 'forest' to 'no forest', rather a gradual increase in the level of future committed die-back: the impacts are more progressive than sudden.

Our results also show that the forest may be committed to some degree of die-back before any is observed. For example, if climate forcing was stabilized at 2050, when tree cover fraction is virtually unchanged from the present day, a significant die-back would still occur subsequently over the next 100–200 years (see Supplementary Fig. S3). This has serious implications for any definition of dangerous climate change, as it means that stabilization of climate does not necessarily mean stabilization of climate impacts. It may not become apparent for some time when a threshold of committed change has been passed.

A further aspect of such committed changes is to consider the potential of the system to recover. Experiments to assess recovery of ecosystems under a return to pre-industrial global climate showed that forests did indeed have the potential for recovery but only on very long (multi-century) timescales (see Supplementary Information). This has implications for temperature-overshoot scenarios. First, from an impacts perspective, once the full change in forest cover has been achieved, the length of time that society has to exist without the forest may be so long that the change is, for practical purposes, irreversible. Second, as the amount of forest cover feeds back on to global atmospheric CO_2 concentration, the long recovery implies that the slow regrowth will make it more difficult to lower CO_2 concentrations and make it more difficult to approach a safe level of CO_2 and warming from above[19].

The concept of committed ecosystem changes applies equally to other biomes and to forest expansion as well as die-back although the response/lag times and impact on carbon storage might be different[20,21]. Figure 3 shows equivalent results for the boreal forest. Using tree cover between 45° and 80° N as a simple measure of northern latitude forest expanse, the dynamic solution shows a steady, but slow, increase in coverage up to the year 2100. Much of this is an intensification of tree cover in existing areas of forest, which occurs more rapidly than an expansion of the treeline. By 2100 we also see a northward expansion of forest cover. The committed state shows much greater expansion, by more than a factor of 3, by 2100. The large difference between realized and committed expansion is due to the slow timescales of areal changes.

The boreal forest region is expected to experience greater than average warming over the twenty-first century[22] and is a region where tree growth is generally more limited by temperature than precipitation. As most GCMs agree qualitatively on warming across high-latitude land areas, it may be expected that results here are more robust across different models (see further discussion in Supplementary Information). Boreal forest expansion has also been seen in other vegetation models[9] and in response to other climate models[16]. Pollen records and tree mortality observations indicate that previous warm periods in the mid-Holocene and medieval warm period did experience greater northward extent of boreal forest[23].

Considering long-timescale changes in ecosystems also has implications for multi-gas mitigation policies owing to the direct physiological effect of CO_2 on vegetation[24]. As ecosystems are also responding to changes in CO_2 concentration, future ecosystem commitments will probably depend not only on the stabilization of radiative forcing, but also the relative contribution of CO_2 and non-CO_2 greenhouse gas mitigation measures. For a given radiative

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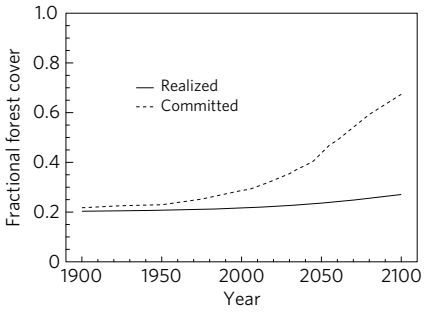


Figure 3 | Dynamic and equilibrium boreal forest extent throughout the simulations. The solid line shows the fractional tree cover (represented as fractional land coverage of both broadleaf and needleleaf trees in the region 45°–80° N) as it evolves dynamically through the SRES A2 simulation and the dashed line shows the committed state corresponding to each year.

forcing, CO_2 and non-CO_2 gases can lead to very different impacts on ecosystems[24]. Elevated CO_2 levels may aid forest resilience (for example, through improved water use efficiency[25]), implying that non-CO_2 reductions may be more effective at reducing committed ecosystem damage. However, quantifying this effect requires much more research. There are also implications for forestry practices, as degraded forest further compounds the risk of committed loss owing to increased vulnerability to fires following disturbance[26].

We have introduced the implications of the hitherto unconsidered application of the concept of committed changes to the terrestrial ecosystem. Although these results are from a single model and hence subject to quantitative uncertainty, we believe the concept of committed changes in the terrestrial biosphere is likely to be robust. The terrestrial biosphere can respond slowly to large, regional-scale forcing, but may not always be in equilibrium with that forcing at any point in time, leading to subsequent commitments to significant future change for decades or centuries following stabilization of forcing. There is a threshold beyond which some die-back is committed and this commitment rises markedly for greater global temperature rise. In our model this threshold is below 2 °C, a threshold often used by policy makers in their definition of dangerous climate change[27], although the quantitative nature of our results carries significant uncertainty. Any subsequent recovery is on such a long timescale as to make the die-back effectively irreversible on human timescales of the next 1–2 centuries.

There has been little or no discussion within the climate or ecosystem research communities on the concept of commitments to ecosystem change due to climate change. Our intention is to draw attention to committed ecosystem changes as an issue requiring serious consideration, and one that requires study with more than a single model. With increasing policy focus on climate mitigation and stabilization of climate change, quantifying such committed changes will make valuable contributions to our understanding of dangerous climate change, and to aiding development of mitigation policies. We argue that committed ecosystem changes, in addition to realized changes, should be considered in any definition of dangerous climate change. Weighing the cost of emissions reductions against the cost of climate damage may lead to very different conclusions for terrestrial ecosystems if committed ecosystem changes are considered in preference to the usual transient response.

Methods

HadCM3LC is a coupled climate/carbon cycle GCM including a dynamic vegetation model. It is able to reproduce many aspects of observed change such as the twentieth-century temperature and CO_2 record[28], observed sensitivity of CO_2 to El Nino and large volcanic eruptions[29]. We base our experiments here on the coupled HadCM3LC transient CO_2-only simulation of C4MIP (ref. 6). This experiment enables us to assess the transient response of ecosystems to the business-as-usual SRES A2 emissions scenario[30]. The changes throughout this experiment give us a projection of the state of the biosphere at any given time during the simulation. We will refer to such a state as the 'dynamic' or 'realized' state—that is, the state that occurs at a point in time as the system evolves but is not necessarily in steady state or in equilibrium with ambient climate or CO_2 levels. Owing to long timescales of response of vegetation, we use an accelerated equilibration technique (see Supplementary Methods) to determine the eventual biosphere state if the forcing was held constant at a given point in time. We will refer to this as the 'equilibrium' or 'committed' state. The difference between the two is therefore a measure of the un-realized but committed change.

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Author contributions

C.J. experiment design, analysis, C.J. and J.L. analysis and text, S.L. carried out model simulations, R.B. advice on design, analysis and text.

Additional information

Supplementary information accompanies this paper on www.nature.com/naturegeoscience. Reprints and permissions information is available online at http://npg.nature.com/reprintsandpermissions. Correspondence and requests for materials should be addressed to C.J.

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FEB 28 2014

To: Regional Director, Fish and Wildlife Service, Lakewood, Colorado

From: Field Supervisor, Colorado Ecological Services Field Office, Lakewood, Colorado

Subject: Intra-Service Section 7 Conference Opinion on the proposed Issuance of a Section 10(a)(1)(A) Enhancement of Survival Permit for Lesser Prairie-Chicken to Western Association of Fish and Wildlife Agencies (WAFWA).

This document transmits the U.S. Fish and Wildlife Service's (Service) conference opinion for the proposed issuance of a 10(a)(1)(A) Enhancement of Survival Permit to Western Association of Fish and Wildlife Agencies (WAFWA) for incidental take of the lesser prairie-chicken (*Tympanuchus pallidicinctus*) (LEPC) pursuant to the proposed Range-wide Oil and Gas Candidate Conservation Agreement with Assurances (CCAA) dated February 28, 2014. This conference opinion is pursuant to section 7 of the Endangered Species Act of 1973, as amended (16 U.S. C. 1531 et seq.) (ESA).

WAFWA has applied to the Service for a section 10(a)(1)(A) enhancement of survival permit (permit) to authorize incidental take of LEPC within the Covered Area, which includes lands encompassed by the currently estimated occupied range of the LEPC plus 10 miles around that range (EOR+10), which includes Kansas, Colorado, Oklahoma, New Mexico, and Texas. LEPC is a candidate for listing pursuant to the ESA. As a condition of the proposed permit, WAFWA would be responsible for implementing the Range-wide Oil and Gas Candidate Conservation Agreement with Assurances (CCAA) (WAFWA 2013).

The LEPC is a Federal candidate species and currently is not listed as federally threatened or endangered pursuant to the ESA. LEPC habitat and historical range has diminished substantially and there is concern for the species' continued survival. In 2012, the Service issued a proposed rule to list the LEPC as threatened on December 11, 2012 (77FR73828). The Service announced the re-opening of the public comment period for the 4(d) rule on January 29, 2014 (79FR4652).

The CCAA and its proposed permit will address incidental take of the LEPC should it become listed during the term of the CCAA. CCAAs provide an effective mechanism for the conservation of rare or imperiled species, including species that are candidates for protection

under the ESA. This conference opinion was prepared using information from the CCAA and its accompanying Environmental Assessment (EA), *The Lesser Prairie-Chicken Range-wide Conservation Plan* (RWP)(Van Pelt et al. 2013), the proposed listing rule (77FR73828), and other sources of information referenced below.

The Service has determined there are three other species of fish, wildlife, and plants that are listed or candidate under the ESA that occur in or near the action area that could be affected by the implementation of the CCAA. Those species include:

- Sprague's pipit (*Anthus spragueii*)
- Northern aplomado falcon (*Falco femoralis septentrionalis*)
- Black-footed ferret (*Mustela nigripes*)

The Service anticipates that the proposed action may affect, but is not likely to adversely affect these species due to lack of overlapping suitable habitat within the action area, local extirpations, and differences in habitat preferences. Therefore, these three species will not be addressed further in this conference opinion. Should any information reveal that any of these species may be adversely affected by the implementation of the proposed action while the permit is in effect, the Service will reinitiate this consultation and address any concerns, as appropriate.

This conference opinion may be confirmed as a biological opinion issued through formal consultation if the LEPC is listed in the future. If the Service reviews the proposed action and finds that there have been no significant changes in the action as planned or in the information used during the conference, the Service will confirm the conference opinion as the biological opinion and no further section 7 consultation will be necessary on the project.

CONFERENCE OPINION

DESCRIPTION OF THE PROPOSED ACTION

Action Area

The action area includes the Covered Area, which includes non-Federal lands within the estimated occupied range of the LEPC plus 10 miles around that range (EOR+10), as shown in Figure 1. The Covered Area encompasses approximately 40,149,404 acres across parts of Colorado, Kansas, New Mexico, Oklahoma, and Texas. The buffer around the range provides for shifts in the estimated occupied range over time due to changes in habitat, movements of birds, and detectability of birds in areas of low population density. The Covered Area is divided into four ecoregions that reflect the different ecotypes across the LEPC range: mixed grass prairie, sand sagebrush prairie, shinnery oak prairie, and shortgrass/CRP mosaic.

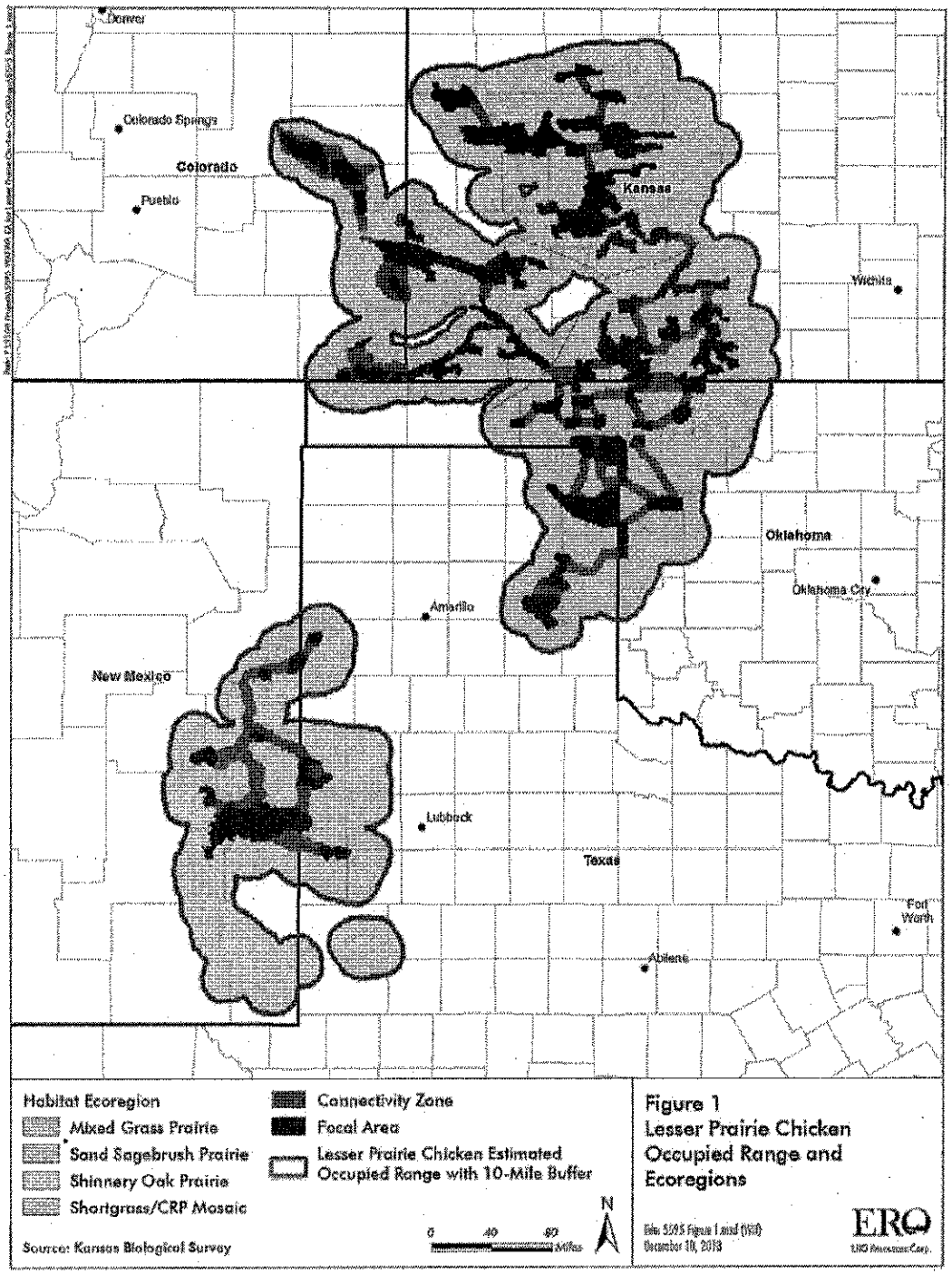


Figure 1. Map of Covered Area for CCAA (Van Pelt et al. 2013).

Proposed Action

The proposed action is the issuance of a section 10(a)(1)(A) enhancement of survival permit and the approval of the CCAA between the U.S. Fish and Wildlife Service (Service), WAFWA (Permit Holder), and participating oil and gas companies (Participants). The CCAA has been developed to provide for the conservation needs of the LEPC while allowing for oil and gas development activities within the Covered Area in Colorado, Kansas, Oklahoma, New Mexico, and Texas. The Covered Area includes the estimated currently estimated occupied range plus 10 miles (EOR+10). The CCAA would have a duration of 30 years.

The CCAA would allow any non-Federal property owner (Participant) to voluntarily enroll their property under the CCAA. WAFWA would enroll cooperating Participants into the CCAA through issuance of Certificates of Inclusion (CIs) and would provide technical assistance. Participants would commit to implement conservation measures that benefit the LEPC by avoiding and minimizing impacts to LEPC habitat and by avoiding and minimizing disturbance impacts and threats to LEPC. Where impacts cannot be avoided or minimized, the Participant will be responsible for paying mitigation fees to WAFWA that will provide for offsite mitigation practices designed to improve LEPC habitat, especially in high priority areas. In return for implementing the conservation measures, the Service would provide the Participants assurances that, for the duration of the CCAA and its associated Section 10(a)(1)(A) permit, no additional conservation measures or additional land, water, or resource use restrictions beyond those voluntarily agreed to and described in the CCAA would be required by the Service should the LEPC become listed in the future, unless otherwise agreed to by Participant.

The CCAA addresses oil and gas activities that have the potential to cause specific threats to LEPC, including seismic and land surveying, construction, drilling, completion, and workovers (recompletion), routine operations and maintenance, and oil and gas remediation and restoration. Further descriptions on these oil and gas activities are provided in Appendix A.

The CCAA tiers to, and incorporates the RWP, which is a conservation strategy and framework developed by WAFWA (Van Pelt et al. 2013). The CCAA uses the same goals, conservation measures, impact metrics, and conservation delivery system as the RWP. The goal of the RWP is to conserve the LEPC for future generations while facilitating continued and uninterrupted economic activity throughout the entire five-state LEPC range. The RWP identifies a two-pronged strategy for LEPC conservation: (1) the coordinated implementation of incentive-based landowner programs, and (2) the implementation of a mitigation framework that reduces threats to the LEPC and provides resources for off-site conservation.

Project Goals

The CCAA incorporates the project goals identified in the RWP. The overall project goal in the RWP is a desired population of 67,000 birds, as an annual spring time average, to be achieved within the first 10 years of the RWP. This population goal represents an increase of

9.4 percent from the current 10-year average of 60,702 birds (Van Pelt et al. 2013). This goal was determined sufficient to meet the following population objectives: 1) to increase populations numbers to ensure a sustainable long-term population within each of the four delineated ecoregions for the next 10 years of the RWP implementation; 2) to maintain and expand the current distribution of the LEPC across its estimated occupied range with some expansion into the area identified as current occupied range buffered by 10 miles; and 3) to maintain higher population sizes in areas where they currently occur and are stable.

Additional population and habitat goals have been identified in the RWP. These goals work collectively towards supporting the overall population goal of 67,000 birds, as an annual spring time average, within a 10-year period, and include the following:

- Ecoregion Population Goals – The four ecoregion goals, as annual spring time averages, were established as follows and will be adjusted, as appropriate, through adaptive management in order to maintain the species for the first 10 years of the implementation of the RWP:

  - Sand shinnery oak ecoregion—8,000 birds
  - Sand sagebrush ecoregion—10,000 birds
  - Mixed grass prairie ecoregion—24,000 birds
  - Short grass/CRP mosaic prairie ecoregion—25,000 birds

- Focal Area Goals – The focal area goals were developed based on best available science on minimum sizes of LEPC habitat, movements, survival, and population status and trends, and include the following:

  - Average size of focal areas should be at least 50,000 acres
  - Goal of at least 70 percent good to high quality habitat within each focal area
  - Focal areas should strive to be <20 miles apart to provide connectivity for genetic and population support.

- Connectivity Zone Goals – The connectivity zones goals were developed based on best available science regarding minimum sizes of habitat blocks and LEPC movements, and include the following:

  - At least 40 percent good to high quality habitat
  - No greater than 2 miles between habitat patches
  - Minimum of five miles in width
  - Few or no barriers to LEPC movement
  - Connectivity zones connecting focal areas should provide suitable habitat to support movements by LEPC.

- Focal Area and Connectivity Area Habitat Goals - The RWP identifies a goal of having sufficient habitat in focal areas to sustain 75 percent of the desired population.

This goal translates into the equivalent of a combined 4,972,800 acres of quality LEPC habitat within the focal areas. The habitat to sustain the remaining 25 percent of the population goal (1,243,136 acres) would be maintained elsewhere within connectivity zones and the remaining EOR+10. The composition of each reporting unit will also be evaluated to assess progress towards achieving the stated habitat goals of 70 percent and 40 percent quality habitat for focal areas and connectivity zones, respectively.

- Focal Area and Connectivity Area Development Impact Goals - The development impact goals for focal areas and connectivity zones in the RWP are no more than 30 percent development impacts in focal areas and no more than 60 percent development impacts in connectivity zones. Where those development goals are surpassed for an individual reporting unit, the habitat goals under the plan cannot be met. In that case, remediation of existing impacts will be required for further development. The remediation offset units should be generated from the same reporting unit as the new impact, but if that is not possible they can originate from a nearby reporting unit within the same ecoregion.

- Stronghold Goals – The stronghold goal is that one or more strongholds will be established in each of the four ecoregions in the Covered Area. Each stronghold will provide a minimum of 25,000 acres of high quality habitat, or up to 50,000 acres if in lower quality habitat, and should contain at least 6-10 leks each, with at least 6 males/lek.

- Conservation Practices (Mitigation) Goals – On areas where conservation practices are implemented, the goals of the conservation practices are: 1) to maintain optimum habitat in 3 of 5 years when it existed at the baseline and was the desired outcome identified in the associated management plan, and 2) to improve vegetation structure by 25 percent over the baseline, if it was a desired outcome identified in the associated management plan.

The proposed action utilizes a combination of conservation measures, the mitigation framework, and an adaptive management strategy to achieve the identified goals. The proposed action is summarized in the following text (specific details of the proposed action of the RWP are provided on pages of 66 – 135 of RWP).

Conservation Measures

The CCAA contains conservation measures that provide for avoidance and minimization of impacts to LEPC habitat, avoidance and minimization of collisions and other threats, and avoidance and minimization of disturbances to breeding and nesting LEPC (see complete list of conservation measures below): With the conservation measures, the standard for avoidance is that no impacts are expected to occur wherever feasible alternatives are available to avoid the impacts. The standard for minimization is that impacts will be

minimized through design, siting and other available methods, but some impact is expected to remain. For those Mitigation will be utilized to offset any remaining impacts.

To summarize, the conservation measures specify that oil and gas development should avoid high priority LEPC areas, namely focal areas, connectivity zones, and within 1.25 miles of known leks that have been active in the past 5 years, and should instead be focused in lands with existing impacts (e.g., developed oilfields) or cultivation (i.e., row-crops). The conservation measures also specify that impacts of oil and gas development should be minimized by reducing the area of surface disturbance through directional drilling and clustering of facilities as well as by use of common rights-of-way for infrastructure such as roads, pipelines, and power lines, etc. The conservation measures address mortality and injury threats by providing guidance to reduce collision risks with new distribution lines, fences, and other structures in the vicinity of active leks. The conservation measures also provide measures to avoid and minimize disturbances to LEPC during the lekking, nesting, and brooding seasons within 1.25 miles of active leks (e.g., occupied in the past 5 years). For operation and maintenance activities that must occur during the breeding season within 1.25 miles of an active lek, the conservation measures require that activities cannot occur during the primary lekking time of 3:00 am to 9:00 am. (Specific conservation measures are provided in greater detail in *Conservation Measures* section below).

The Covered Area has been prioritized and categorized into four levels of LEPC habitat; this system is known as the Crucial Habitat Assessment Tool (CHAT). CHAT 1 is the top priority category and represents the focal areas for LEPC conservation. CHAT 2 represents connectivity areas around the focal areas. CHAT 3 represents predicted high-quality available and potential habitat. CHATs 1 through 3 collectively contain the estimated currently occupied range. CHAT 4 represents a 10-mile buffer around the currently occupied range and provides for range expansion and project planning. Focal areas and connectivity zones are shown in Figure 1.

Although oil and gas development activities can occur throughout the Covered Area, the strategy encourages conservation of higher quality habitat, namely the focal areas and connectivity zones, by requiring higher mitigation fees in the focal areas and connectivity zones and, conversely, identifies areas more suitable for development by requiring lower mitigation fees in areas of lower quality habitat (CHAT 3 and 4) in the Covered Area. The prioritization of CHAT areas in this manner incentivizes oil and gas development to avoid the higher quality areas.

For the purposes of the CCAA, habitat impacts are defined as potential LEPC habitat that has been rendered unusable by LEPC based on direct or indirect habitat loss related to development. Indirect habitat loss refers to avoidance by LEPC of potential habitat around an impact site, such as a well pad, road, transmission line, etc. These estimates of indirect habitat loss are based on previous observations of avoidance behavior by LEPC. Habitat impacts are assessed by the number of acres that will be affected, the habitat quality at the impact site, and the CHAT category at the impact site. Impact Buffers are the defined

distances around Impact Activities within which LEPC habitat is considered to be impacted as a result of the Impact Activity. These buffers vary in size depending on the type of Impact Activity, as shown in Table 1.

Table 1. Impact Buffer distances for different types of developments established under the WAFWA LEPC Mitigation Framework to define impacts (Van Pelt et al. 2013, p. 95).

Type of Impact	Buffer distance feet (meters)
Oil and gas pads and small compressor stations*	656 (200)
Wind turbines	2188 (667)
Transmission lines ≥69 kV	1312 (400)
Distribution lines <69 kV	33 (10)
Tall vertical structures (>150 ft.)	2188 (667)
Secondary roads	220 (67)
Primary roads	1640 (500)
Industrial buildings and other compressor stations**	2188 (667)
Residential buildings (houses)	436 (133)
Private roads (ranch roads, etc.)	33 (10)

**Includes compressor stations with foot prints of <5 acres that are muffled to <75dB at 30 feet.*

***Includes all other compressor stations and electrical substations.*

Mitigation Framework

Where avoidance and minimization of impacts is not possible, the mitigation framework quantifies the impacts of development, quantifies the amount of mitigation necessary to offset the impacts, and then requires the payment of mitigation fees by Participants for the implementation of mitigation actions.

The mitigation framework will concentrate habitat offset units in the focal areas and the connectivity zones, allowing for the restoration, enhancement, and maintenance of large blocks of habitat needed by LEPC while also minimizing the presence of small local patches of habitat that may not support desired population levels. The location of the offset units will be focused primarily in the focal areas and connectivity zones and the Advisory Committee will be responsible for prioritizing the selection of offset projects, as described in the RWP.

All offset units generated with these funds must be of the same or higher habitat quality than impacted acreage, as determined through the use of the CHAT and on-site vegetation monitoring, thereby ensuring a significant conservation benefit for LEPC when impacts do

occur. Impact units are valued based on the cost of implementing the conservation practices (i.e., mitigation) that provide a benefit to the LEPC, plus a WAFWA administrative cost of approximately 12.5 percent of this value.

The mitigation framework evaluates impacts based on the amount of surface disturbance that results from development plus the impact buffer surrounding infrastructure, as well as the quality of the habitat impacted. As a result, a Participant that constructs a new 5-acre oil and gas well pad will mitigate approximately 31 acres, based on the 200- meter impact buffer around the well pad (although this area may be reduced if the well pad is constructed within the impacted area associated with existing infrastructure). The mitigation framework also requires that impacts will be offset with greater amounts of mitigation and will utilize a 2:1 ratio, ensuring that mitigation efforts are greater than impacts and resulting in a net conservation benefit for the LEPC habitat and, ultimately, LEPC populations. Thus, to construct a 5-acre well pad in unimpacted habitat, a Participant will be required to provide funds to allow for the mitigation of between 50 and 78 acres (depending on the multiplier for the specific CHAT category). To account for variations in the quality of on-site vegetation, the number of impacted acres is adjusted by site condition scores to create "impact units."

The mitigation framework further provides a conservation benefit to the LEPC by providing WAFWA with an early commitment of funds by Participants for use towards securing landowner contracts and generating offset units. Initially, Participants will remit an enrollment fee of $2.25 per year for every enrolled acre for the first three years of enrollment (for a total of $6.75 per acre). Secondly, a Participant is assessed a mitigation fee once development is proposed and the value of the mitigation fees assumes that all impacts will be permanent. Thus, mitigation fees are calculated by multiplying the number of offset units by 25, which provides sufficient funds to create a non-wasting endowment to provide permanent conservation offsets. Therefore, in the example above, a Participant developing a five-acre well pad must remit funds based on the value of between 1,250 and 1,950 impacted acres (50 and 78 acres respectively multiplied by 25), as adjusted by site condition scores.

Twenty-five percent of the resulting habitat offset units are targeted toward permanent easements to support long-term conservation and population strongholds. There is no minimum acreage for permanent easements, beyond the minimum size of 160 acres for all contracts, but WAFWA will focus and prioritize the identification of parcels that will result in large blocks of permanent easements. The remaining 75 percent of the offset units are targeted toward short-term contracts (5 to 10 years). Mitigation will also include reclamation or remediation of inactive or abandoned facilities and infrastructure that are under the control of the Participants, in compliance with applicable state rules and regulations.

The impact units must be balanced with an equal number of offset units in the same CHAT category or better each year, thereby providing for the maintenance of suitable habitat within the Covered Area. In order to provide time for WAFWA to generate offset units during the first year of the CCAA, it incorporates the RWP's waiver period until March 30, 2015 in which impacts from limited oil and gas development could go unmitigated for the first year

of its implementation. The Service is concerned about the potential of a year of unmitigated impacts combined with other ongoing impacts, the potential continuation of drought in large areas of the LEPC range, and potential continuing decline of LEPC population numbers. Accordingly, the Service and WAFWA developed a strategy to allow time for WAFWA to develop offset units while still limiting the amount of unmitigated impacts to occur during the first year. The Permit will contain stipulations for limiting the amount of unmitigated take during any given time within the first year. WAFWA will provide results from the 2014 spring surveys to the Service by July 1, 2014. If the 2014 spring surveys indicate a 20 percent decline in the population from the 2013 population estimate (14,092 birds or less), the following limitations on take would apply: no more than 5,109 Habitat Units of unmitigated take in CHAT; 7,664 Habitat Units in CHAT 2; and 11,495 Habitat Units in CHAT 3, from the effective date of the Permit through March 30, 2015. During that period, if any take of Habitat Units is documented to be fully offset, further take of Habitat Units would be authorized, as long as the unmitigated limit of Habitat Units in each CHAT is not exceeded. The Permit will also require WAWFA to provide reports to the Service every four months after July 1, 2014, and through March 30, 2105, with documentation of the level impacted Habitat Units and credited Offset Units in each of CHATs 1-3.

Description of Conservation Practices for Mitigation (Generation of Offset Units)

For the mitigation, conservation practices were selected that will develop conditions to: 1) provide shelter, cover, and food in proper amounts, locations and times to sustain LEPC during all phases of its life cycle; or 2) enable LEPC movement. These practices are the same conservation practices that are used by the Natural Resources Conservation Services (NRCS) to benefit the LEPC, as provided in their Lesser Prairie-Chicken Initiative (LPCI) (Service 2013).

The primary conservation practices that will be used for the generation of offset units will be: prescribed grazing, prescribed burning, brush management, and range planting. Other conservation practices, such as fencing, water wells, access control, etc., are also identified within the mitigation framework, although these practices serve to facilitate the implementation of the primary practices; these facilitating conservation practices are provided in Appendix B of this conference opinion.

WAFWA will develop a management plan for the lands where mitigation practices will occur under the CCAA (i.e., enrolled in the mitigation framework). The management plan will identify upland wildlife habitat concerns on the specified properties and will identify specific conservation practices to address those concerns that will be implemented as part of the mitigation framework. All management plans will use the NRCS core practice of Upland Wildlife Habitat Management (645) and will add Prescribed Grazing (528) when livestock are present, in order to determine which, if any, facilitating conservation practices are needed, as well as the extent, location, and timing of facilitating practices to ensure that LEPC habitat is maintained or improved following application. The following text describes the specific primary conservation practices:

- **Conservation Practice: Upland Wildlife Habitat Management (645).** This conservation practices will provide and manage upland habitats and connectivity within the landscape for wildlife. This core management practice will be applied or maintained annually to treat and manage wildlife, in particular LEPC resource concerns identified during the conservation planning process. This practice shall be used alone, or in combination with facilitating practices, shall result in a conservation system that will enable the planning area to meet or exceed the minimum quality criteria for upland wildlife habitat.

- **Conservation Practice: Prescribed Grazing (528).** This conservation practice will manage the harvest of vegetation with grazing and/or browsing animals to improve or maintain desired species composition and vigor of plant communities and improve or maintain quantity and quality of forage for grazing and browsing animals' health and productivity. At the individual project and landscape scale, the use of this practice standard is expected to produce a mosaic of vegetation structure and composition to benefit the LEPC by creating, as needed at the appropriate scale, areas of greater forb and resulting insect production and creating areas of higher residual cover for nesting birds. Management planning will identify the limiting biological conditions for the LEPC and create a grazing management system to address the limiting biological conditions for the LEPC.

- **Conservation Practice: Prescribed Burning (338).** This conservation practice will manage controlled fire applied to predetermined areas. The purpose is to create the desired plant community phase consistent with the ecological site description that is preferable LEPC habitat and to enhance and produce desirable or needed plant communities for all phases of LEPC life cycle. Prescribed burning will improve forage production quantity and/or quality and will facilitate distribution of grazing to target the maintenance or creation of desired LEPC habitat. Suppression of fires on the landscape has created a plant community less responsive to prescribed fire and has allowed for invasion of undesirable species such as Eastern red cedar and non-native grass species.

- **Conservation Practice: Brush Management (314).** This conservation practice will manage or remove woody plants, including those that are invasive and noxious. The purpose is to restore or enhance the desired native plant community that is consistent with the ecological site description, and which provides the most suitable habitat for the LEPC and other wildlife species. Specifically, it may be used for the purpose of removing undesirable post-settlement conifers such as juniper, Eastern red cedar or deciduous species such as mesquite and black locust that have encroached into habitats being restored for LEPC habitat.

- **Conservation Practice: Range Planting (550).** This conservation practice will establish adapted perennial or self-sustaining vegetation such as grasses, forbs,

legumes, and shrubs. This practice is used to restore important native habitats by converting cropland to grasslands to meet habitat requirements for LEPC. The purpose is to restore the native plant community to a condition similar to the ecological site description reference state for the site, provide or improve forages for livestock and browse or cover for wildlife, and reduce erosion by wind and/or water.

The conditions at the offset units will be monitored annually. As mentioned above, the goals of the conservation practices are: 1) to maintain optimum habitat in 3 of 5 years when it existed at the baseline and was the desired outcome identified in the associated management plan; and 2) to improve vegetation structure by 25 percent over the baseline when anticipated in the associated management plan.

Adaptive Management

The CCAA (and RWP) have identified activities or situations known as changed circumstances that would trigger the adaptive management process and other corrective actions to be implemented in response to these changed circumstances. Changes identified through a formal evaluation process would affect implementation of the CCAA by adjusting conservation measures for new Participants. For existing Participants, mitigation fees would be reviewed on an annual basis, as described in the CCAA, and can be adjusted annually up to 3 percent to account for inflation and up to 4 percent to account for changes in mitigation fees.

The CCAA will utilize adaptive management strategies to allow for mutually agreed-upon changes to the conservation measures to occur in response to changing conditions or new information, including those identified during monitoring and from emerging science. The primary reason for using adaptive management is to allow for changes in the conservation measures that may be necessary to reach the stated long-term goals. Under adaptive management, the mitigation and conservation activities implemented under the RWP will be monitored to identify whether or not they are producing the required results. Some of the factors that will be evaluated regularly by the various committees include LEPC population sizes, progress toward habitat goals, conservation practice costs, avoidance of high priority conservation areas, management prescriptions, etc.

Among the items being evaluated, breeding population sizes will be annually assessed by drawing comparisons between the 3-year average and the 50 percent of the population goal for each ecoregion. Every five years, a more rigorous review will occur to assess each WAFWA prescribed conservation practice, the appropriateness of the reporting area locations, and progress towards achieving the stated population and habitat goals of the RWP. The conservation practices implemented during the previous five years will be evaluated by the WAFWA committees based on their ability to achieve the desired vegetation parameters. New standards will be considered for 1) practices that have not maintained habitat quality in at least 3 of 5 years where it existed at baseline and 2) practices that have not resulted in at least a measurable level of improvement in habitat quality where

such improvements were the desired outcome of a management plan. The composition of each reporting unit will also be evaluated to assess progress towards achieving the stated habitat goals of 70 percent and 40 percent quality habitat for focal areas and connectivity zones, respectively. Identified activities that will be evaluated in the adaptive management process are provided in Appendix C of this conference opinion.

Annual monitoring and reporting of populations and mitigation sites will be conducted by WAFWA. WAFWA will also conduct compliance monitoring.

Conservation Measures

This CCAA incorporates the conservation strategy in the RWP, which includes a series of conservation measures intended to avoid and minimize impacts on LEPCs and their habitat, as well as mitigate any remaining habitat impacts. As indicated by each conservation measure below, some of the avoidance and minimization measures are required, identified below as "Required," and some may be applied at the discretion of the Participant, identified below as "Discretionary." If a Participant chooses not to implement a discretionary conservation measure, the Participant will need to mitigate for resulting impacts. The required mitigation fees will be determined based on the amount of habitat that would be impacted after the application of those measures, the CHAT categories that the impacts are located within, and the habitat quality based on the habitat evaluation conducted using the Habitat Evaluation Guide (HEG), as described in Appendix A of the CCAA.

A) Habitat Loss and Fragmentation. Habitat loss and fragmentation are primary threats to the LEPC. Impact Activities (construction of oil and gas pads, compressor stations, private roads (e.g., lease roads), distribution lines, and industrial building) may contribute to habitat loss and fragmentation. The following Conservations Measures apply to any action that could further negatively impact LEPC habitat or connectivity between blocks of LEPC habitat to receive coverage under the CCAA.

1) Avoidance

a) Use available options to avoid focal areas, connectivity zones, or within 1.25 mi of known leks that have been active at least once within the previous five years, as well as project sites dominated by tracts of native grass and shrublands (see the 2013 CHAT, state fish and wildlife agency staff, and Section XIV (Development Procedures for more information). (Discretionary)

b) Focus development on lands already altered or cultivated (such as row-crop agriculture or developed oilfields), and away from areas of undeveloped native grass or shrublands. Select fragmented or degraded habitats over relatively intact areas, and select sites with lower LEPC habitat potential over sites with greater habitat potential. The NRCS Ecological Site Descriptions,

where available, are a good indicator to use (see Appendix C of the RWP). (Discretionary)

2) Minimization

a) Use common rights of way for multiple types of infrastructure in locating new roads, fences, power lines, well pads, flow lines, compressors, and other associated oil and gas infrastructure. (Discretionary)

b) Site projects to minimize new habitat disturbance by increasing the amount of overlap between existing fragmentation and associated impact buffers. (Discretionary)

c) Reduce impacts through the use of directional drilling and clustering where feasible or in locating facilities to reduce habitat loss and fragmentation of habitat. (Discretionary)

d) Minimize use of herbicide treatments and limit this use to the footprint or right of way for the project. Where practical and applicable, utilize an herbicide that is targeted for specific use and spot treatments as opposed to a broadband herbicide and broadcast treatments. Apply in conditions that minimize drift. (Required)

3) Mitigation – Any impacts not offset by the avoidance or minimization measures above will be mitigated as follows:

Participants will provide for mitigation of habitat loss associated with new Impact Activities through the payment of Mitigation Fees as described in Section XIII(B) of the CCAA, Appendix B of the CCAA, and Exhibit B of the CI. WAFWA will apply Mitigation Fees to generate offset units using the process described in Appendix I of the RWP. (Required)

B) Collision and Other Direct and Indirect Sources of Mortality. LEPC have been shown to collide with fences, power lines, and cars. Power lines also serve as potential perch sites for raptors that may prey on LEPCs. It is also possible for LEPC to get caught and drown in human-made water sources (e.g., tanks).

1) Avoidance

a) Locate new roads, fences, power lines, well pads, flow lines, compressors, and other associated oil and gas infrastructure and their impact buffers outside focal areas, connectivity zones, or in other areas identified as high probability lek and nest habitat by 2013 CHAT categories 1-3. (Discretionary)

b) Bury new distribution lines within 1.25 mi of leks active within the previous 5 years. If new distribution lines cannot be buried, justification must be provided to and approval obtained from WAFWA prior to construction of such new distribution lines. (Required)

2) Minimization

a) Use common rights of way for multiple types of infrastructure. (Discretionary)

b) To minimize transmission line footprint, utilize mono-pole construction for new electrical transmission lines within 2013 CHAT categories 1-3. (Required)

c) Utilize horizontal drilling, pad drilling (multiple wells per pad), and common tank batteries where feasible with regulatory approval to minimize new surface disturbance within 2013 CHAT categories 1-3. (Discretionary)

d) Install appropriate fence markings along new fences that are under the control of the enrolled Participant within one quarter (1/4) mile of a lek that has been recorded as active within the previous 5 years. (Required)

e) During the LEPC breeding season (March 1-July 15), minimize traffic volume, control vehicle speed, control access where feasible, and avoid off-road travel within focal areas and areas identified as high probability lek and nest habitat by the 2013 CHAT. (Required)

f) Within 1.25 mi of leks, it is recommended to install raptor deterrents on new electrical distribution and transmission poles as indicated by Avian Power Line Interaction Committee (APLIC) Suggested Practices for Raptor Protection on Power Lines: The State of the Art in 2006, as amended. If further studies are completed that demonstrate significant benefits to the LEPC, this Conservation Measure may be amended for newly Enrolled Property and new enrollments by existing Participants. (Discretionary. Mitigation is not required.)

g) Provide escape ramps, rafts or ladders, depending on configuration, in exposed, human-made water containment sources on Enrolled Property under the control of the enrolled Participant. (Required)

3) Mitigation – Any impacts not offset by the avoidance or minimization measures above will be mitigated as follows:

Participants will provide for mitigation of habitat loss associated with new Impact Activities through the payment of Mitigation Fees as described in Section XIII(B) of the CCAA, Appendix A of the CCAA, and Exhibit B of the CI. WAFWA will apply Mitigation Fees to generate offset units using the process described in Appendix I of the RWP. (Required)

C) Disturbance of Breeding, Nesting, and Brooding Activity. Disruption of courtship displays and nesting hens through construction and maintenance activities or equipment and infrastructure that emit loud noises may have direct impact on LEPC reproductive output.

1) Avoidance

a) Avoid non-emergency operations, construction and maintenance activities, where humans are present, during lekking, nesting, and brooding season (March 1–July 15) within 1.25 mi of leks recorded active within the previous 5 years. (Discretionary, see Section XII(C)(2)(a))

Emergency operations are allowed. Emergency operations are those activities unexpectedly and urgently required to prevent or address immediate threats to human health, safety, or property; the environment; or national defense or security.

Participants must record the dates, duration and purpose of any emergency operations that occurred between March 1 and July 15 within 1.25 miles of leks recorded as active within the previous 5 years and provide that documentation to WAFWA within 30 days. (Required)

b) Seismic surveys and similar activities that require extensive off road travel shall not be conducted in rangeland or planted grass cover during the lekking nesting and brooding season (March 1–July 15) within 1.25 mi of leks recorded active within the previous five years and lek surveys shall be required in CHAT categories 1-3 prior to any breeding season Seismic surveys. (Required subject to exception in Section XII(C)(2)(c)).

2) Minimization

a) For non-emergency operations, construction and maintenance activities, where humans are present, that **cannot be avoided and must occur** during March 1 - July 15, restrict activities between the hours of 3:00 am and 9:00 am in areas within 1.25 mi of leks that have been recorded as active within the previous 5 years. (Required)

b) Institute noise abatement year-round for new facility operations (post-construction, post-drilling, post-completion, and post-recompletion) located within 1.25 mi of a lek recorded as active within the previous 5 years. Noise from these new facilities shall not exceed 75 dB when measured at Participant's property line or any point greater than 30 feet from the facility boundary. This minimization measure is required unless other regulations require lower noise levels. If new scientific information becomes available supporting lower or higher decibel limits through the adaptive management process, this Conservation Measure may be amended for both new and existing Participants as provided in Section XXII (Modification of the CCAA and Amendment of the Permit). In the event of changes in noise limits for existing Participants, WAFWA and the Participants will agree upon a timeline for implementing those changes. (Required)

c) If a complete lek survey is conducted for the proposed seismic activity area, WAFWA shall consider, on a case by case basis, the application of seismic methodologies that minimize LEPC disturbance off road travel during the lekking, nesting and brooding season (March 1-July 15) within 1.25 miles of leks recorded as active within the previous 5 years. Daily timing restrictions for lek disturbance (3:00am-9:00 am) must be observed within 1.25 miles of leks recorded as active within the previous five years. (Required)

Commitments of Participants, WAFWA, and the Service

In addition to the commitment to implement the conservation measures (described above), the Participants also commit to specific items that are provided in greater detail in the CCAA but summarized here: enter into a Certificate of Inclusion with WAFWA, pay appropriate Enrollment and Mitigation Fees, provide access to WAFWA for species and vegetation monitoring, provide access to WAFWA and the Service for compliance monitoring, and report annually to WAFWA.

In addition to the commitment to implement the conservation measures, WAFWA commits to specific items that are provided in greater detail in the CCAA but summarized here: hold the 10(a)(1)(A) permit issued by the Service, implement and administer the CCAA, implement the mitigation projects, conduct species and compliance monitoring on Enrolled Properties, address non-compliance issues, provide annual reporting, and maintain confidentiality of information regarding Participants.

In addition to issuing the 10(a)(1)(A) permit, the Service commits to specific items that are provided in greater detail in the CCAA but summarized here: provide oversight of the implementation of the CCAA, conduct compliance monitoring when accompanied by WAFWA, participate with WAFWA in resolution of non-compliance issues, and maintain confidentiality of information regarding Participants.

STATUS OF THE SPECIES

Status of the Species is an analysis of appropriate and best available scientific information on the species' life history, habitat and distribution, and other data on factors related to its survival and recovery. This analysis considers the effects of past human and natural activities or events that have led to the current condition of the species.

We are including only a summary of the status of the species, as provided by NRCS (2013). For detailed information on the status of the species, including species habitat description, life history, population dynamics, status and distribution, and analysis of the existing threats and conservation challenges to the species, refer to the proposed rule to list the LEPC as a Threatened species published in the Federal Register on December 11, 2012 (77FR73828) and the documents listed in the Literature Cited section. No critical habitat has been proposed for this species.

Species Description and Life History

The LEPC is a species of prairie grouse endemic to the southern high plains of the United States, commonly recognized for its stout build, ground-dwelling habit, and lek mating behavior. Plumage is characterized by a cryptic pattern of alternating brown and buff-colored barring, and is similar in mating behavior and appearance, although somewhat lighter in color, to the greater prairie-chicken (*T. cupido pinnatus*). Males have long tufts of feathers on the sides of the neck (pinnae) that are erected during courtship displays. Pinnae are smaller and less prominent in females. Males also display brilliant yellow supraorbital eyecombs and dull reddish esophageal air sacs during courtship displays (Copelin 1963, p. 12; Sutton 1977, entire; Johnsgard 1983, p. 318). Female LEPCs are generally smaller than the males. Adult body length varies from 38 to 41 centimeters (cm) (15 to 16 inches (in)) (Johnsgard 1973, p. 275; Johnsgard 1983, p. 318), and body mass varies from 734 to 813 grams (g) (1.6 to 1.8 pounds (lbs)) for males and 628 to 772 g (1.4 to 1.7 lbs) for females (Giesen 1998, p. 14).

The preferred habitat of the LEPC is native short- and mixed-grass prairies having a shrub component dominated by *Artemesia filifolia* (sand sagebrush) or *Quercus havardii* (shinnery oak) (Donaldson 1969, pp. 56, 62; Taylor and Guthery 1980a, p. 6; Giesen 1998, pp. 3–4). Small shrubs are important for summer shade (Copelin 1963, p. 37; Donaldson 1969, pp. 44–45, 62), winter protection, and as supplemental foods (Johnsgard 1979, p. 112). Historically, trees and other tall woody vegetation were largely absent from these grassland ecosystems, except in canyons and along water courses. Landscapes supporting less than 63 percent native rangeland appear incapable of supporting self-sustaining LEPC populations (Crawford and Bolen 1976a, p. 102).

LEPCs are polygynous and exhibit a lek mating system using leks where males traditionally gather to conduct a communal, competitive courtship display using their specialized plumage and vocalizations to attract females for mating. Males exhibit strong site fidelity to their

display grounds (Copelin 1963, pp. 29–30; Hoffman 1963, p. 731; Campbell 1972, pp. 698–699) whereas females, due to their tendency to nest within 2 miles of a lek (Suminski 1977, Riley 1978, Giesen 1994a, p. 97), also may display fidelity to nesting areas but the degree of fidelity is not clearly established (Schroeder and Robb 2003, p. 292). However, Haukos and Smith (1989, p. 418) observed that female LEPCs are more likely to visit older, traditionally used lek sites than temporary, nontraditional lek sites (i.e., those used for no more than 2 years).

Leks are normally located on the tops of wind-swept ridges, exposed knolls, sparsely vegetated dunes, and similar features in areas having low vegetation height or bare soil and enhanced visibility of the surrounding area (Copelin 1963, p. 26; Jones 1963a, p. 771; Taylor and Guthery 1980a, p. 8). Females arrive at the lek in early spring after the males begin displaying, with peak hen attendance at leks typically occurring in early to mid-April (Copelin 1963, p. 26; Hoffman 1963, p. 730; Crawford and Bolen 1975, p. 810; Davis *et al.* 1979, p. 84; Merchant 1982, p. 41; Haukos 1988, p. 49). Within 1 to 2 weeks of successful mating, the hen will select a nest site, normally within 1 to 3 km (0.6 to 2 mi) of a lek (Copelin 1963, p. 44; Giesen 1994a, p. 97), construct a nest, and lay a clutch of 8 to 14 eggs (Bent 1932, p. 282; Copelin 1963, p. 34; Merchant 1982, p. 44; Fields 2004, pp. 88, 115–116; Hagen and Giesen 2005, unpaginated; Pitman *et al.* 2006a, p. 26). Nesting is generally initiated in mid-April and concludes in late May (Copelin 1963, p. 35; Snyder 1967, p. 124; Merchant 1982, p. 42; Haukos 1988, pp. 7–8).

LEPCs forage during the day, usually during the early morning and late afternoon, and roost at night (Jones 1964, p. 69). Diet is very diverse, primarily consisting of insects, seeds, leaves, and buds and varies by age, location, and season (Giesen 1998, p. 4). They forage on the ground and within the vegetation layer (Jones 1963b, p. 22) and are known to consume a variety of invertebrate and plant materials. Generally, chicks and young juveniles tend to forage almost exclusively on insects, such as grasshoppers and beetles, and other animal matter while adults tend to consume a higher percentage of vegetative material (Giesen 1998, p. 4).

Nests generally consist of bowl-shaped depressions in the soil (Giesen 1998, p. 9) and are lined with dried grasses, leaves, and feathers. Adequate herbaceous cover, including residual cover from the previous growing season, is an important factor influencing nest success, primarily by providing concealment of the nest (Suminski 1977, p. 32; Riley 1978, p. 36; Riley *et al.* 1992, p. 386; Giesen 1998, p. 9).

LEPCs have a relatively short lifespan and high annual mortality. Campbell (1972, p. 694) estimated a 5-year maximum lifespan, although an individual nearly 7 years old has been documented in the wild by the Sutton Avian Research Center (Sutton Center) (Wolfe 2010).

Historic and Current Distribution

Prior to description by Ridgeway in 1885, most observers did not differentiate between the LEPC and the greater prairie-chicken. Consequently, estimating historical abundance and occupied range is difficult. Historically, the LEPC is known to have occupied native rangeland in portions of Colorado, Kansas, Oklahoma, Texas, and New Mexico. Records also indicate occurrence in Nebraska based on at least four specimens known to have been collected near Danbury in Red Willow County during the 1920s (Sharpe 1968, p. 50) however, none have been observed in Nebraska since that time.

Johnsgard (2002, p. 32) estimated the maximum historical range of the LEPC to have encompassed some 260,000 to 388,500 sq km (100,000 to 150,000 sq mi), with about two-thirds of the historical range occurring in Texas. Taylor and Guthery (1980a, p. 1, based on Aldrich 1963, p. 537) estimated that, by the 1880s, the area occupied by LEPC was about 358,000 sq km (138,225 sq mi), and, by 1969, they estimated the occupied range had declined to roughly 125,000 sq km (48,263 sq mi) due to widespread conversion of native prairie to cultivated cropland. Taylor and Guthery (1980a, p. 4) estimated that, by 1980, the occupied range encompassed only 27,300 sq km (10,541 sq mi), representing a 90 to 93 percent reduction in occupied range since pre-European settlement and a 92 percent reduction in the occupied range since the 1880s.

In 2007, cooperative mapping efforts by species experts from five State Fish and Wildlife Agencies, in cooperation with the Playa Lakes Joint Venture, re-estimated the maximum historical and occupied ranges. Their estimated total maximum historically occupied range is approximately 466,998 sq km (180,309 sq mi). The approximate occupied range, by State, based on this cooperative mapping effort was 4,216 sq km (1,628 sq mi) in Colorado; 29,130 sq km (11,247 sq mi) in Kansas; 8,570 sq km (3,309 sq mi) in New Mexico; 10,969 sq km (4,235 sq mi) in Oklahoma; and 12,126 sq km (4,682 sq mi) in Texas. Since 2007, the occupied and historical range in Colorado and the occupied range in Kansas have been adjusted to reflect new information. The currently occupied range in Colorado is now estimated to be 4,456 sq km (1,720 sq mi), and, in Kansas, the LEPC is now thought to occupy about 34,479 sq km (13,312 sq mi). The approximate current occupied LEPC range is 70,600 sq km (27,258 sq mi) (Playa Lakes Joint Venture 2007).

The overall distribution of LEPC within all States except Kansas has been reduced since European settlement, and the species is generally restricted to variously-sized habitat patches within a highly fragmented landscape (Taylor and Guthery 1980a, pp. 2–5) or areas with significant CRP enrollments that were initially seeded with native grasses (Rodgers and Hoffman 2005, pp. 122–123). The estimated current occupied range, based on cooperative mapping efforts described above, and as derived from calculations of the area of each mapped polygon using geographical information software, represents about an 84 percent reduction in overall occupied range since pre-European settlement.

In the spring of 2012, the States, in conjunction with the Western Association of Fish and Wildlife Agencies, implemented a range-wide sampling framework and survey methodology using small aircraft (McDonald et al., 2013). This aerial survey protocol was developed to provide a more consistent approach for detecting range-wide trends in LEPC population abundance across the occupied range. The goal of this survey was to estimate the abundance of active leks and provide information that could be used to detect trends in lek abundance over time. The results of the spring 2012 aerial survey indicated a range-wide population estimate of 34,440 birds and 2,930 leks. In 2013, the surveys were repeated and results indicate a range-wide population estimate of 17,616 birds constituting a 49 percent decline from the 2012 estimate, and 2,036 leks constituting a 30 percent decline from 2012 (MacDonald et al. 2013).

Reasons for Decline and Threats to Survival

The reduction in the range of the LEPC is primarily due to habitat loss and habitat fragmentation resulting from a variety of mechanisms, such as conversion of native prairie and grassland to cropland; improper grazing, haying, and herbicide spraying that reduces LEPC habitat quality; long-term fire suppression and encroachment by invasive woody plants; habitat fragmentation caused by energy development and petroleum production and associated vertical infrastructure such as turbines, towers, and utility lines; and prolonged drought.

Vertical structures such as power poles, transmission lines, etc. to accommodate energy transmission historically were not common in LEPC habitat or on or near lek sites. The presence of those structures now provides perches for hawks and owls to sit, observe, and hunt LEPC's habitat, making loss of chicks and adults much more likely than before. Additionally, due to decreases in land parcel size over time, more fencing is needed to delineate property boundaries creating a network of low perches for predators across the landscape that historically did not occur at today's scale.

Grazing, haying and mowing can contribute to increased predation as well by reducing grass height that LEPCs have historically relied upon for food and cover. If these activities are applied at an inappropriate frequency, intensity, time, or duration across a larger landscape, the collective effect of loss of cover (to hide from predators), thermal cover (to stay warm in the winter), and reduced food sources can result in significant harm to local populations.

This habitat loss is a significant threat to the LEPC because the species requires large parcels of intact native grassland and shrubland to maintain self-sustaining populations. Due to its reduced population size and ongoing habitat loss and degradation, the LEPC's resiliency to recover from adverse effects resulting from present and future impacts and persist in the long term is compromised. Many of these threats may exacerbate the normal effects of periodic drought on lesser prairie-chicken populations. In many cases, the remaining suitable habitat has become fragmented by the spatial occurrence of these individual threats. As a group, prairie grouse may be particularly sensitive to habitat fragmentation due to their short

dispersal distances and landscape-scale habitat requirements (Braun et al. 1994). Habitat fragmentation can be a threat to the species through several mechanisms: remaining habitat patches may become smaller than necessary to meet the requirements of individuals and populations, necessary habitat heterogeneity may be lost to areas of homogeneous habitat structure, areas between habitat patches may harbor high levels of predators, and the probability of recolonization decreases as the distance between suitable habitat patches expands.

Threats Specific to Oil and Gas Development

Because LEPCs require large contiguous tracts of prairie ecosystems to fulfill their life history requirements, the cumulative impacts of well pads, pipelines, roads and increased traffic, overhead transmission lines, compressor stations, and production facilities not only result in direct habitat loss, but also results in fragmentation of remaining suitable habitat (Pitman et al. 2005). Collisions with overhead transmission lines cause direct mortality to LEPCs and may further limit LEPC populations (Bidwell et al. 2003). Transmission lines also provide perches for raptors, which could potentially increase the mortality rate of LEPCs (Bidwell et al. 2003). Prairie grouse have been shown to avoid roads, power lines, and other man-made infrastructures (Pitman et al. 2005). Crawford and Bolen (1976) noted that LEPC leks adjacent to heavily traveled roads were abandoned at a higher rate than those found further from anthropogenic disturbance. The effect of daily vehicular traffic associated with maintenance of oil and gas operations along these road networks can also impact breeding activities and may further decrease the availability of habitat (Braun et al. 2002).

While all the effects of oil and gas development on LEPCs are not understood, recent studies have suggested that development of oil and gas resources negatively impacts prairie grouse, particularly during the breeding season (Lyon and Anderson 2003; Pitman et al. 2005). Noise associated with oil field activities may impact breeding activities if mating display vocalizations are disrupted by background noise (Davis 2006). Braun et al. (2002) noted that sage-grouse lek attendance was lower on breeding grounds located in close proximity to active mineral resource developments compared to less disturbed lek sites. Smith et al. (1998, p. 3) observed that almost one-half, 13 of 29, of the abandoned leks examined in southeastern New Mexico in an area of intensive oil and gas development had a moderate to high level of noise. Braun (1986) speculated that if noises associated with oil field activity deter recruitment of yearling sage-grouse males to breeding grounds, leks may become extinct.

Studies to assess whether sounds from oil and gas exploration may have played a role in the abandonment of a number of historically active lek sites in southeast New Mexico show that abandoned lek sites were exposed to higher ambient noise levels than active sites (Hunt 2004). The same study also reports a significantly higher number of operating wells within one mile of abandoned lek sites. Whether this pattern of lek abandonment reflects sensitivity to noise or some other form of disturbance associated with intensive oil and gas development, or is a response to factors not associated with drilling, remains unknown.

However, all of these studies emphasize the importance of taking behavioral avoidance into consideration when assessing development impacts on LEPC habitat.

ENVIRONMENTAL BASELINE

The environmental baseline includes past and present impacts of all Federal, state, or private actions in the action area; the anticipated impacts of all proposed Federal actions in the action area that have undergone formal or early section 7 consultation; and the impact of state and private actions that are contemporaneous with the consultation process. The environmental baseline defines the current status of the species and its habitat in the action area to provide a platform to assess the effects of the action now under conference.

Estimates of Current LEPC Populations

As provided in the RWP, WAFWA has developed an estimate of the densities of LEPC for each of the ecoregions. The density estimate utilized in their analysis is based on a reconstruction of LEPC populations across the range by Garton (2012). This reconstruction used LEPC ground survey data and aerial survey data collected across all four ecoregions. Depending on the ecoregion, this collective long-term average population estimate represents a period of 13-22 years from 1990 to 2012. During this period, populations ranged from roughly 37,000 to 84,000 birds, and that population estimate is representative of past and future conditions, including the population goals within the RWP. The density estimate uses the Garton average population estimate divided by the area of suitable habitat as predicted by a Maximum Entropy lek habitat model developed by USGS (Jarnevich et al. unpublished data) (Table 2). It conservatively represents all potential take resulting from development or habitat and population management actions within that suitable habitat. The MaxEnt lek habitat model used estimates approximately 30 perecent of the areas within the EOR+10 is currently suitable habitat for LEPCs. This analysis assumes that take of LEPCs is a function of the average lifespan or generation time for the species. Mean lifespan is calculated based on Farner (1955) as $0.4343/\log10(S) = 1.95$ years (95%CIs = 0.99 to 5.6 years), where S represents the estimated yearling survival rate of 60 percent. Note that these estimates have not been updated to include the 2013 aerial surveys, which show a 50 percent decline in LEPC numbers rangewide (MacDonald et al. 2013).

Table 2. Estimated density of LEPCs within suitable habitat identified in each ecoregion. The population estimates represent long-term averages based on Garton (2012) and the acreages of suitable habitat are based on the lek habitat model developed for the CHAT (Van Pelt et al. 2013, p. 130).

	LEPC Suitable Habitat Density per 640 acres				
	MIXED GRASS (1990-2012)	**SAND SAGE (1990-2012)**	**SHORTGRASS (1999-2012)**	**SHINNERY OAK (1999-2012)**	**Suitable Habitat Avg**
Population Estimate	32117	6118	24271	4967	67473
Suitable Habitat Acreage	3,823,650.82	1,661,175.92	1,169,141.06	5,409,080.10	12063047.9
Suitable Habitat Density	5.38	2.36	13.29	0.59	3.58

Description of Overall Impacts from Oil and Gas Development to LEPC Habitat within the Covered Area

Well densities have increased dramatically throughout many portions of lesser prairie-chicken range. For example, the amount of habitat fragmentation due to oil and gas extraction in the Texas panhandle and western Oklahoma associated with the Buffalo Wallow oil and gas field within the Granite Wash formation of the Anadarko Basin has steadily increased over time. In 1982, the rules for the Buffalo Wallow field allowed one well per 130 ha (320 ac). In May of 2005, the Texas Railroad Commission changed the field rule regulations for the Buffalo Wallow oil and gas field to allow oil and gas well spacing to a maximum density of one well per 8 ha (20 ac) (Texas Railroad Commission 2007). When fully developed at this density, the region will have experienced a 16 fold increase in habitat fragmentation in comparison with the rates allowed prior to 2005.

Impacts from oil and gas development and exploration is thought to be the primary reason responsible for the species' near absence throughout previously occupied portions of the Carlsbad BLM unit in southeastern New Mexico (Belinda 2003, p. 3). This reasoning is supported by research examining lesser prairie-chicken losses over the past twenty years on Carlsbad BLM lands (Hunt and Best 2004, pp. 114-115). In this study, factor analysis (a statistical method used to describe variability among observed variables in reference to a number of unobserved variables) of characters associated with active and abandoned leks was conducted to determine which potential causes were associated with the population decline. Those variables associated with oil and gas development explained 32 percent of observed lek abandonment (Hunt and Best 2004) and the consequent population extirpation.

In the BLM's RMPA some limited protections for the lesser prairie-chicken in New Mexico are provided by reducing the number of drilling locations, decreasing the size of well pads, reducing the number and length of roads, reducing the number of powerlines and pipelines, and implementing best management practices for development and reclamation (BLM 2008, pp. 5-31). The RMPA provides guidance for management of approximately 344,000 ha (850,000 ac) of public land and 121,000 ha (300,000 ac) of Federal minerals in Chaves, Eddy, Lea, and Roosevelt Counties in New Mexico. Implementation of these restrictions, particularly curtailment of new mineral leases, would be greatest in the Core Management and Primary Population Areas (BLM 2008, pp. 9-11). The Core Management and Primary Population Areas are located in the core of the lesser prairie-chicken occupied range in New Mexico. The effect of these best management practices on the status of the lesser prairie-chicken is unknown, particularly considering about 60,000 ha (149,000 ac) have already been leased in those areas (BLM 2008, p. 8).

Oil and gas development and exploration is ongoing in the remaining states although the precise extent is currently unknown. Some development is anticipated in Baca County, Colorado, although the timeframe for initiation of those activities is uncertain (CPW 2007, p. 2). In Oklahoma, oil and gas exploration statewide continues at a high level. Since 2002, the average number of active drilling rigs in Oklahoma has steadily risen (Boyd 2009, p. 1). Since 2004, the number of active drilling rigs has remained above 150, reflecting the highest level of sustained activity since the 'boom' years from the late 1970s through the mid-1980s in Oklahoma (Boyd 2007, p. 1).

Existing Conservation Efforts for LEPC

Although the LEPC is not federally listed, a number of conservation efforts, including numerous state, Federal, and private programs, are currently in place that provides conservation benefits to the species and directly address threats to the LEPC. These programs provide technical and financial assistance to landowners for habitat management for LEPC. Other programs provide assurances to landowners and industries that if LEPC considerations are included in management activities, future management can continue in this manner even if LEPC are listed by the USFWS. Several programs address industry siting, best management practices, and avoidance, minimization and voluntary mitigation. Additional programs provide for direct management of LEPC habitat on public or other lands within LEPC range.

Five federal agencies have programs or initiatives that directly relate to delivery of LEPC habitat improvement or assurances. The NRCS initiated the Lesser Prairie-Chicken Conservation Initiative (LPCI) in 2008 to increase the abundance and distribution of the LEPC and its habitat while promoting the overall health of grazing lands and the long-term sustainability of ranching operations. The Farm Service Agency (FSA) administers a voluntary program for agricultural landowners that address threats to LEPC, including agricultural conversion, by providing a pathway to incentivize landowners to take cropland

out of production and plant back into grassland. The Service's Partners for Fish and Wildlife Program improves, restores, and protects habitat on private lands through partnerships with landowners. The Bureau of Land Management (BLM) and the U.S. Forest Service (USFS) manage lands within occupied LEPC habitat through various management plans. These conservation efforts are described in detail in the proposed listing rule (77FR73828) and the RWP (Van Pelt et al. 2013). Combined with the RWP, these programs provide for a high level of certainty and predictability to the USFWS regarding LEPC conservation.

Methodology for Estimating Current Level of Development Impacts in Action Area

Oil and gas activity has occurred throughout the range of the LEPC, more intensely in certain areas, as described in the Service's proposed listing rule (Service 2012, p. 73785). The Service is utilizing the analysis conducted by WAFWA in their RWP to estimate the existing level of development impacts within the Action Area. The following text summarizes WAFWA's methodology and results (Van Pelt et al. 2013) for their analysis. Specific details on this analysis are provided on pages 131-134 of the RWP.

WAFWA's analysis evaluated the current level of impacts by infrastructure type for all industries within each ecoregion within the EOR+10. Existing infrastructure or developments were identified based on publicly available GIS data for Colorado, Kansas, New Mexico, Oklahoma and Texas. The sources and dates for these data sources are described in detail on pages 131–134 of the RWP. These datasets represent the best available data on developments within the region, but in many cases, the spatial and attribute error rates of these datasets are undefined. It is expected that the mitigation framework under the RWP and this CCAA will incentivize industry to provide better data on existing developments and will improve the assessment of impacts over time. In addition to the infrastructure data sources, this analysis uses data from the 2013 CHAT, which includes the focal areas (CHAT 1), connectivity zones (CHAT 2) and the remainder of the EOR+10.

All available spatial data for active oil and gas wells, wind turbines and cell towers, transmission and distribution lines and roads was used. Each type of development was buffered in ArcGIS 10 (ESRI 2011) using the appropriate impact buffer distanced defined within the RWP, as shown in Table 1. The total acreage of impacted habitat for each impact type within focal areas (CHAT 1), connectivity zones (CHAT 2) and CHAT Categories 3 and 4 within each ecoregion and across ecoregions were summarized, as provided in Table 3. The total number of acres impacted by all infrastructure types within each ecoregion and across all ecoregions (Table 4) also were summarized. The calculation of all infrastructure impacts includes any overlap of multiple infrastructure impacts counted only once. The total acres impacted by each infrastructure type and the proportion of acres infrastructure within each ecoregion were also calculated.

Estimates of Current Level of Development Impacts in Action Area

A summary of the total number of acres impacted by various types of development within each LEPC ecoregion is provided in Table 4. Impact acres are defined by the area within the impact buffer distances for each development location. The acreage of all infrastructure impacts is less than the sum of the categories due to the overlap of impact buffers between types of impacts.

Table 3. Summary of total number of acres impacted by various types of development within each of the ecoregions. Impact acres are defined by the area within with impact buffer for each development location (Van Pelt et al. 2013, p. 136).

Infrastructure Type	CHAT Category	Mixed Grass	Sand Sage	Shortgrass	Shinnery Oak	Total Acres by Impact
Oil and Gas	CHAT 1	113,548	107,721	34,387	30,230	**2,562,112**
	CHAT 2	76,132	6,221	4,989	7,444	
	CHAT 3 & 4	675,826	350,351	330,270	824,993	
Wind and Vertical Structures	CHAT 1	12,936	11,105	8,023	1,390	**503,270**
	CHAT 2	13,122	949	731	4,220	
	CHAT 3 & 4	187,738	72,767	90,918	99,371	
Transmission	CHAT 1	33,923	72,666	28,947	32,120	**1,819,096**
	CHAT 2	22,344	11,931	6,686	38,190	
	CHAT 3 & 4	388,513	269,359	261,079	653,339	
Roads	CHAT 1	284,871	154,472	171,646	98,717	**6,206,543**
	CHAT 2	174,047	39,608	26,893	120,865	
	CHAT 3 & 4	1,542,104	1,059,147	1,125,614	1,408,559	
All Infrastructure	CHAT 1	415,940.3	321,603	232,480	154,247	**9,874,839**
	CHAT 2	257,963.9	55,221	37,232	160,515	
	CHAT 3 & 4	2,477,513.5	1,585,759	1,642,870	2,533,494	
	Impact Acres	**3,151,418**	**1,962,583**	**1,912,582**	**2,848,257**	
	Total Acres	12,827,528	8,349,445	8,822,405	10,682,886	
	% Impacted	**24.6**	**23.5**	**21.7**	**26.7**	

At the scale of the entire EOR+10, roads are the most common source of infrastructure impacts. When impact types are considered separately without overlap, roads account for 56 percent, oil and gas development account for 23 percent and transmission and distribution lines account for about 16 percent of infrastructure impacts acres for this analysis. Spatial data for distribution lines are very sparse and this impact is probably underestimated. However, distribution lines are generally sited along roads so the lack of data for this infrastructure type likely has little impact on the overall analysis. Wind turbines and other

vertical structures such as cell and radio towers are the least common source of infrastructure impact on the landscape, accounting for less than 5 percent.

As shown in Table 3, the level of existing development impacts within the Action Area for each of the ecoregions is relatively similar, ranging from 21.7 to 26.7 percent. This value could suggest that approximately 75 percent of remaining land within each ecoregion is presently available as LEPC habitat. However, not all the remaining area within the Action Area contains suitable LEPC habitat, and furthermore, much of this area is present as smaller areas of often fragmented habitat. A spatial analysis conducted by the Service (Service 2012, p. 73856) of the currently existing habitat within the occupied LEPC range determined that 99.8 percent of the suitable habitat patches were less than 5,000 acres in size. Only approximately 70 patches remain that were equal to, or larger than, 25,000 acres.

A comparison of the current amount of development impacts between the different CHAT categories shows that there are significant differences between the focal areas (CHAT 1), connectivity zones (CHAT 2), and the remainder of the EOR+10 (CHAT 3 & 4), as shown in Table 4. These differences between the CHAT categories are to be expected as the best remaining habitat for LEPCs is present in areas least impacted by infrastructure.

Table 4. The total acres impacted by each infrastructure type by CHAT category, where acreage is defined by impact buffer distances around each impact type (Van Pelt et al. 2013).

Infrastructure Type	**CHAT 1**	**CHAT 2**	**CHAT 3&4**
Oil and Gas	285,886	94,786	2,181,441
Wind and Vertical Structures	33,454	19,022	450,794
Transmission	167,656	79,151	1,572,289
Roads	709,706	361,413	5,135,424
All Infrastructure Impacts	1,124,270	510,933	8,239,636
Acres per CHAT category	7,104,000	3,107,840	30,939,520*
% Impacted Acres	**15.8**	**16.4**	**26.6**

*The acreage of all infrastructure impacts is less than the sum of the categories due to the overlap of impact buffers between types of impacts

EFFECTS OF THE ACTION

This conference opinion evaluates the effects of the implementation of the CCAA on the LEPC and its habitat. In the event that LEPC becomes listed under the ESA, a variety of oil and gas development and management actions have the potential to result in take of the species. Field development (well pads, roads) and facility construction and ancillary facilities such as compressor stations, pumping stations and electrical generators would result in direct loss of habitat and habitat fragmentation if these activities occur in or near LEPC habitat. Construction activities, maintenance activities, seismic surveys, off-road travel, and other activities would result in disturbance of lekking behavior, breeding, and nest and brood

attendance. Direct mortality from development may occur, for example, from collisions with structures, fencing or vehicles. In addition, construction and maintenance activities related to development may result in increased travel on primary and secondary roads that lead to increased disturbance beyond what is expected from these roads. And finally, management activities relating to conservation practices (mitigation), such as prescribed grazing, prescribed burning, brush management, and range planting, all have the potential to result in some low levels of take.

WAFWA's Analysis for Estimating Future Oil and Gas Related Impacts

This section analyzes the potential impacts to LEPCs as a result of the Covered Activities. We rely on the analysis conducted by WAFWA in their RWP (Van Pelt et al. 2013) to estimate the future development impacts within the Action Area. However, there are several challenges related to estimating take that are unique to the LEPC. First and foremost, the scale of the analysis is large, covering parts of five states. In addition, like most birds, the extent of the range of the species is very much in flux from year to year. Detecting the birds in low density habitat around the periphery of the range is difficult and the species is highly mobile. And finally, LEPC is difficult to survey, and those surveys occur only when the birds come to leks in the spring. Until very recently, survey methodology and intensity varied widely between states, but recent range-wide aerial surveys have begun to solve that problem. As a result of these factors, this analysis will focus on estimating the potential acreage impacted by those development and management activities and will estimate take based on estimates of LEPC density. This analysis considers everything that is not within an existing impact buffer, including cropland, as potential habitat. Cropland ranks as low quality habitat under the habitat metrics in the RWP.

The intent of this analysis is to estimate potential take on 10, 20, and 30 year timeframes. The CCAA evaluates development levels based on 30-year projections. However, energy markets and technology, climatic conditions, land use patterns and practices, and ultimately, LEPC populations vary over time. It is important to recognize that although this analysis assumes that any development action that occurs outside of buffers from pre-existing impacts may result in incidental take of LEPC, such development will not necessarily result in incidental take of LEPC throughout all of EOR+10.

General Methodology of WAFWA's Estimation of Future Oil and Gas Related Impacts

The following text summarizes WAFWA's methodology (WAFWA 2013) for their analysis. Specific details on this analysis are provided on pages 129-134 of the RWP. The WAFWA analysis involved an estimate of the LEPC population density as well as an estimate of the rate and extent of habitat loss resulting from oil and gas development.

Well permitting data from each state was utilized to define the number of active wells within the EOR+10 as a starting point for forecasting future development. Wells are the most common type of oil and gas impact on the landscape and are the basis for the calculations

below. Oil and gas development does include other types of infrastructure, some of which have very small impact buffers, such as privately maintained roads and distribution lines that are often covered by the larger well impact buffers. In the case of downstream infrastructure, such as pipelines and compressors, any buried infrastructure does not constitute a source of long-term habitat loss for LEPCs. However, there is sufficient scientific data suggesting that compressor stations result in nesting habitat loss through avoidance. Smaller compressors that may be muffled to 75dB were given the same impact buffer as a well (i.e., 200 m), but large compressors that are louder and much less common on the landscape have been assessed a correspondingly larger impact buffer.

The U.S. Energy Information Administration produced the Annual Energy Outlook 2013 (AEO2013), which includes long-term projections of energy supply, demand, and prices out to 2040. These projections include forecast of both U.S. natural gas production (AEO2013:78) and the production of petroleum and other liquids (AEO2013:81). These projections are based on both high and low price scenarios for each resource. The highest price scenario was used to reflect a maximum projected development scenario. The estimated annual growth rates for oil production and gas production were calculated by first summing the year 2040 estimates for oil production and gas production. This sum was then divided by the sum of the current estimates to determine the overall combined growth rate for oil and gas production for the 30-year period. The overall combined growth rate was then divided by 30 to determine the average annual combined growth rate for oil and gas production. This result was then divided by two to determine the average annual growth rates for oil production and gas production independently. The annual growth rate for the high oil and high gas price scenario is 0.0549. Production growth rate was assumed to result in a corresponding increase in wells drilled.

The number of wells was forecasted for 10, 20 and 30 year durations across the EOR+10 as: projected wells = existing wells + (existing wells X annual growth rate X years), as shown in Table 5. Because of the lack of data to forecast where future development will occur within the region, well numbers were forecasted across the entire EOR+10 and not individual ecoregions or CHAT categories.

Table 5. The projected number of new wells across the LEPC EOR+10 over 10, 20, and 30 year periods based on the high oil and gas price scenario projected from the Annual Energy Outlook 2013.

Projected New Wells Drilled Across the EOR+10 under the EIA High Price Scenario		
10 Year	**20 Year**	**30 Year**
59,804	**119,608**	**179,416**

To estimate the number of acres impacted by each well:

- The new wells drilled within each ecoregion were identified for the most recent year available;
- Each well was buffered by 200 m, and the total number of acres within those buffers was calculated;
- Any existing or overlapping new impacts were removed from the total number of acres within the buffers; and
- This total was divided by the number of new wells.

Based on this calculation, each well impacted an average of 17.94 acres of previously unimpacted habitat. This average level of impact was utilized to calculate the acres of habitat loss.

Results of WAFWA's Analysis of Estimation of Future Oil and Gas Related Impacts

The results of WAFWA's analysis are listed in Table 6, which include the estimation of the acres impacted by new wells and the potential number of LEPCs that may be taken by that development across the EOR+10. This table includes the estimation of the acres impacted by new wells based on an average 17.94 acre impact, and the potential number of LEPCs that may be taken by that development across the EOR+10, given an average lifespan of 1.95 years. These estimates represent the high oil and gas price scenario from AEO2013.

Table 6. WAFWA's estimation of acres of potential LEPC habitat and individual LEPC impacted resulting from projected oil and gas development forecast (Van Pelt et al. 2013).

Acres of Potential LEPC Habitat Impacted Across the EOR+10 under the EIA High Price Scenario		
10 Year	20 Year	30 Year
1,072,883	2,145,767	3,218,716

Number of LEPCs Potentially Taken Across the EOR+10 under the EIA High Price Scenario		
10 Year	20 Year	30 Year
3,593	7,185	10,778

Assumptions of the Estimates of Future Oil and Gas Related Impacts

The values represented in Table 6 represent a worst reasonable case scenario. The actual

acres of LEPC habitat to be impacted are likely to be less, although we do not have a specific means to estimate and calculate the benefits of the Conservation Measures. Reasons for considering that actual habitat losses will be less than the values provided in Table 6 are provided in the following text:

- The analysis assumed the high price oil and gas scenario for entire 30 years of the CCAA.

- The analysis does not include the benefits of implementation of the conservation measures (e.g., overlap of well pads with areas of existing disturbance or infrastructure) and other factors.
- The analysis did not attempt to identify areas where development would not occur either due to geological or administrative limitations.

- As drilling and production technology improve in the future, oil and gas producers will continue to increase production per surface location, which will likely result in meeting future demands for energy with fewer surface and habitat impacts.

- The analysis assumed that any development action that occurs outside of pre-existing impact buffers may result in loss of LEPC habitat. However, much of the habitat within the EOR is not suitable habitat, and development within those areas is not likely to affect LEPC.

- The analysis did not attempt to project where development might occur within the EOR+10 in relation to suitable habitat or otherwise.

- The analysis assumed a single well pad for each surface location. However, where the geology allows, oil and gas producers may drill multiple wells per pad, and this practice is incentivized under the mitigation framework of the CCAA because it reduces the total surface disturbance impacts. Horizontal drill techniques increase siting flexibility, which may decrease the average number of acres of habitat impacted by a well or pad.

- The CCAA also incentivizes siting new well pads within prior impacts. This framework incentivizes siting in unsuitable or low quality habitat by imposing higher mitigation fees for siting wells in higher quality habitat.

However, the Service notes that this estimate by WAFWA for oil and gas development only included impacts resulting from the construction of new well pads (200 m impact buffer) and did not include other infrastructure. WAFWA considers that impacts from new roads and transmission lines relating to oil and gas development are generally within the impact buffers for the new well pads.

In an effort to quantify benefits of reducing habitat loss through the co-location of

infrastructure, WAFWA (2013a) conducted a GIS analysis of the level of overlap of existing infrastructure overlap within the EOR+10. At the scale of the entire EOR+10, and when considering all impact types, there is an average 12 percent overlap of existing current infrastructure based on the difference between the sum of all individual impact types and the total impacted acres summarized including overlap. This level of existing overlap suggests that collocation of different types of infrastructure is relatively uncommon overall prior to the implementation of the RWP.

When this same analysis is done for recent development of infrastructure types such as oil and gas, there is significant evidence that buffer overlap reduces the overall impact acres of development. When the acreage impacted by new oil and gas wells in the most recent year available (2012 for CO, KS, NM, TX, and 2009 for OK) was examined, preexisting and adjoining new impacts reduced the overall impact acreage by approximately 58 percent (Van Pelt et al. 2013). Much of this overlap is related to in-field development in high-density crude oil fields. This analysis of recent oil and gas development indicates a strong potential for decreasing surface disturbances through collocation of infrastructure, especially through the mitigation framework in the CCAA (and RWP) that provide financial incentivizes for colocation. Furthermore, collocation is expected to increase with plan implementation.

For our estimate of incidental take for the 30 years of the implementation of the CCAA, we utilized WAFWA's estimates of impacted acres and the birds potentially taken, as provided in Table 6. We then reduced those values by using WAFWA's estimate of reduced surface disturbance (58 percent reduction) due to the use of overlap with existing infrastructure and rights-of-way that is estimated to occur by WAFWA through the implementation of the conservation measures in the CCAA. Additionally, we added the estimated incidental take resulting from implementation of the conservation practices. Our estimates are provided in Table 7.

Table 7. Estimates of acres impacted and anticipated incidental take of LEPC resulting from implementation of CCAA considering benefits of overlap with existing infrastructure (acres in Table 6 x 0.58) plus the effects of conservation practices.

Years	Acres Potential Habitat Impacted by new wells - Considering Overlap Benefit	Number of LEPC Potentially Taken by new wells - Considering Overlap Benefit	Number of Birds Potentially Taken by Implementation of Conservation Practices (est.76 birds/yr)	Total Number of Birds Potentially Taken
10	622,272	2,084	760	2,843
20	1,244,545	4,167	1,520	5,687
30	1,866,855	6,251	2,280	8,530

EFFECTS OF IMPLEMENTATION OF CCAA

We have divided discussion of the effects of the implementation of the CCAA into three impacts categories: (I) Impacts relating to LEPC habitat; (II) Impacts relating to mortality and injury of LEPC; and (III) Impacts relating to disturbance of LEPC.

Impact Type: (I) Impacts Relating to LEPC Habitat

Expected Beneficial Effects of CCAA Relating to LEPC Habitat

The implementation of this CCAA will benefit the LEPC through the application of the conservation measures and the mitigation practices that will occur throughout the currently occupied range of the LEPC. The avoidance and minimization measures will reduce the overall level of impacts to LEPC and their habitat. The mitigation framework of the CCAA will provide for the enhancement and restoration of LEPC habitat and will contribute to establishment, augmentation and maintenance of LEPC populations. The adaptive management strategy will monitor and evaluate the mitigation and conservation activities implemented under the CCAA and will adjust these activities accordingly in order to meet the CCAA goals.

Benefits to LEPC habitat from the implementation of the CCAA are summarized as follows:

Avoidance and Minimization

- The CCAA creates financial incentives to Participants to avoid construction of new developments in focal areas, connectivity zones, and other high quality habitat by assigning higher mitigation fees for development in areas with higher quality habitat and in higher priority areas (CHAT 1 and 2). As a result, direct and indirect impacts to LEPC habitat are expected to be greatly reduced as compared to development that would occur without this conservation framework.

- In addition to encouraging development outside high priority habitat and high priority areas, the CCAA also uses the mitigation fee structure to encourage location of new oil and gas development within areas with existing infrastructure (e.g., directional drilling techniques and clustering of facilities) and previously impacted areas by providing reduced mitigation fees in these areas. These measures should minimize habitat losses and fragmentation effects from future oil and gas development. We do not have a specific estimate of the amount by which habitat losses will be reduced, however, we are using the assumption from WAFWA's GIS analysis of more recent oil and gas development in which overlapping with existing infrastructure and colocation reduced the overall surface impact by 58 percent.

- For example, mitigation fees for a 5-acre well pad in the sand sagebrush ecoregion in the CHAT 4 category in low quality habitat could be $1,336, while mitigation fees in

high quality habitat in CHAT 4 area could be $26,729. In comparison, the mitigation fees for a 5-acre well pad in low quality habitat in CHAT 1 category (i.e., focal areas) would be $2,088 while the mitigation fees in high quality habitat in CHAT 1 would be $41,764. As shown in this cost structure, mitigation fees will be reduced substantially if a project occurs within an area of existing impacts. Furthermore, development that is contained within previously impacted habitat will result in no mitigation costs beyond the initial enrollment fees.

- By encouraging development to occur outside of focal areas (CHAT 1) and connectivity zones (CHAT 2), we expect that the result of the implementation of the CCAA will be the retention of higher quality habitat within these areas. These actions should provide for the concentration of larger blocks of high quality habitat and a reduction of the existing habitat fragmentation, providing for better connectivity between the focal areas and areas of population expansion.

- Furthermore, through the focal area and connectivity zone goals in which the focal areas shall have no more than 30 percent in development impacts and the connectivity areas shall have no more than 60 percent in development impacts, the CCAA shall minimize the levels of development impacts that can occur within these high priority areas. Where the 30 percent and 60 percent caps have been reached, remediation of existing development impacts will be required prior to further development. These restrictions on development impacts in these important areas will be maintained during the Waiver Period of the first year of implementation of the CCAA.

- Restrictions on herbicide use that limit herbicide use to the project footprint or rights-of-way will minimize potential impacts that would remove or alter the suitability of LEPC habitat.

As prescribed in the adaptive management table (provided in Appendix C), a number of habitat-related elements in the adaptive management strategy provide for the monitoring and evaluation of habitat and population conditions and for the adjustment of the CCAA operations, as appropriate. Some of these elements will be evaluated annually and others evaluated every 5 years and include:

- Progress made towards the overall population goal and ecoregion population goals
- Evaluation of differentiation of new impacts occurring in different CHAT categories
- Evaluation of level of development impacts in CHAT 1 and 2
- Progress made towards stronghold goals
- Evaluation of emerging science relating to the LEPC and the CCAA.

Mitigation

- In situations when impacts occur that cannot be fully addressed through avoidance and minimization procedures, this CCAA employs a mitigation framework that is a biologically based system that incorporates space, time and habitat quality to quantify both the impacts to habitat (impact units) and improvements to habitat (offset and remediation units). The resulting mitigation practices will result in both improvement of habitat conditions and creation of habitat for the LEPC. Mitigation projects will be focused in the focal areas and connectivity areas, which will provide for better habitat connectivity and the concentration of larger blocks of suitable habitat in these areas, ultimately benefitting LEPC populations.

- The mitigation framework evaluates impacts based on the impact buffer surrounding infrastructure, the size of which varies by infrastructure type. As a result, a Participant that constructs a new five-acre oil and gas well pad will mitigate for a 200 meter buffer, which is approximately 31 acres (although this area may be reduced if the well pad is constructed within the impacted area associated with existing infrastructure).

- The Participant is also required to provide additional mitigation. The mitigation framework assigns an impact multiplier depending on CHAT category of the project site. The impact multiplier ranges between 2.5 for CHAT category 1 and 1.6 for CHAT category 4 that, when averaged across the CHAT categories, produces an average 2:1 mitigation ratio. This 2:1 ratio ensures that mitigation efforts are greater than impacts, resulting in a net conservation benefit for the LEPC habitat, and ultimately LEPC populations. Thus, to construct a five-acre well pad in unimpacted habitat, a Participant will be required to provide funds to allow for the mitigation of between 50 and 78 acres (31 acres multiplied by 1.6 and 2.5, respectively).

- All offset units generated with these funds must be of the same or higher habitat quality than impacted acreage, further ensuring a significant conservation benefit for LEPC when impacts do occur.

- The CCAA and mitigation framework further provide a conservation benefit to the LEPC by providing WAFWA with an early commitment of funds by Participants that provides WAFWA with substantial resources to begin securing landowner contracts and generating offset units. Upon enrollment in the CCAA, Participants will remit enrollment fees of $2.25 per year for every enrolled acre for the first three years of enrollment (for a total of $6.75 per acre).

- Additionally, the value of the mitigation fees assumes that all impacts will be permanent. Thus, fees are calculated by multiplying the number of offset units by 25, which provides sufficient funds to create a non-wasting endowment to provide permanent conservation offsets. Therefore, in the example above, a Participant developing a five-acre well pad must remit funds based on the value of between 1,250

and 1,950 impacted acres (50 and 78 acres respectively multiplied by 25), as adjusted by site condition scores.

- Private land owners will be paid by WAFWA for their generation of offset units. WAFWA will develop a management plan for all enrolled sites that identifies recommended conservation practices. WAFWA will track impacts and monitor the acreages in grassland, cropland, etc. Towards this purpose, vegetation monitoring will be conducted annually on lands enrolled for offset generation to determine habitat quality.
- The ratio of permanent easements and shorter-term habitat offset units (25 and 75 percent, respectively) provides for a combination of conservation. The goal of the permanent easements is to create large, unfragmented blocks of LEPC habitat that contribute to the strongholds in each ecoregion. Short-term contracts provide a level of flexibility in the conservation within the CCAA as mitigation types and locations can be adjusted throughout the focal areas and connectivity zones to meet the conservation needs of the LEPC. Mitigation activities will include conservation practices that are specifically designed to provide conservation benefits for LEPC (e.g., prescribed grazing, prescribed burning, brush management, range planting) (see section below for specifics on conservation practices).

- Additionally, mitigation actions will include the remediation of existing impacts (i.e., removal of infrastructure) by Participants. Removal of infrastructure is expected to both create and improve habitat conditions for LEPC.

- Information obtained through annual range-wide aerial population monitoring and compliance monitoring on enrolled properties by WAFWA will be used in the adaptive management program.

- As prescribed in the adaptive management table (provided in Appendix C), a number of mitigation-related elements in the adaptive management strategy provide for the monitoring and evaluation of habitat and population conditions and for the adjustment of the CCAA operations, as appropriate. Some of these elements will be evaluated annually and others evaluated every 5 years and include:
  - Progress made towards maintaining optimum habitat in 3 of 5 years on offset units, where was identified as desired outcome;
  - Progress made toward 25 percent improvement on vegetation structure on offset unit over baseline, where anticipated in associated management plan;
  - Progress towards annual goals for total restoration and remediation;
  - Evaluation of emerging science relating to conservation practices for the LEPC and the CCAA.

Conservation Practices on Mitigation Properties (Offset Generation Units)

- Benefits of Conservation Practices: Prescribed Grazing

  Prescribed grazing will benefit LEPC habitat and populations by improving or maintaining the composition and vigor of desired plant communities. Management plans developed for prescribed grazing will identify the limiting biological conditions for the LEPC and will create a grazing management system to address the limiting biological conditions for the LEPC. By producing a mosaic of vegetation structure and composition, prescribed grazing will benefit the LEPC by creating areas of higher residual cover for nesting birds and by creating areas with greater forb production, resulting in greater forage by an increased insect production. Conservation measures for prescribed grazing specify that the frequency and duration of grazing will be designed to create or maintain adequate habitat structure. The intensity of grazing will be at a level appropriate for specific lift cycle requirements (i.e., nesting, lekking, brood rearing, etc.). Benefits from the implementation of prescribed grazing are expected to occur within the same season as the implementation of the grazing management plan. Prescribed grazing will help to address the issues of habitat loss and fragmentation.

- Benefits of Conservation Practices: Prescribed Burning

  Prescribed burning will benefit LEPC habitat and populations by improving habitat specifically to enhance and produce desirable or needed plant communities for all phases of LEPC life cycle. Management plans developed for prescribed burning will be developed to identify the conditions of the controlled fire that will be applied to a predetermined area. Management of prescribed burning will typically be coordinated with prescribed grazing, if livestock are present. Prescribed burning will help to facilitate distribution of grazing to target the maintenance or creation of desired LEPC habitat and will restore and/or maintain ecological sites in a shifting mosaic across the landscape (Fuhlendorf and Engle 2004). Prescribed fires generally improve forage production quantity and/or quality for livestock. Improvements in the diversity of sand sagebrush brush communities following prescribed burns were documented for 1 to 3 years following the fire, including forb production, after which vegetation conditions returned to those in the adjacent unburned pastures (Winter et al. 2011). Prescribed fires can result in the reduced suitability of nesting habitat, although this is generally a short-term effect (Winter et al. 2011).

  Suppression of wildfires in the past has resulted in ecological sites that are vastly different from historic plant communities for LEPC and for grazing by large ungulates. Plant productivity, health, and vigor have been reduced due to a lack of fire. Longer fire return intervals have created a plant community less responsive to prescribed fire and have allowed for invasion of undesirable species such as Eastern Red Cedar and non-native grass species. Depending on the site conditions in areas

with invasive shrubs, it may be necessary to cut and remove the shrubs prior to the prescribed burn in order to maintain the desired burn conditions. Conservation measures for prescribed burning specify that implementation of the conservation practice within 0.5 miles of known leks will be deferred until breeding and nesting activities are completed, typically March 1 through July 15. The practice will be designed to create the desired habitat conditions for the LEPC. Prescribed fire will help control these invasive shrubs, helping to address the issues of habitat loss and fragmentation.

- Benefits of Conservation Practices: Brush Management

  Brush management will benefit LEPC habitat and populations by removing undesirable post-settlement conifers (eastern red cedar and juniper) and deciduous species (mesquite and black locust) that have invaded LEPC habitat, often causing the birds to avoid and abandon these areas. The goal of brush management is to restore or enhance the desired native plant community that is consistent with the ecological site description and which provides the most suitable habitat for the LEPC and other wildlife species. Removal of these tall shrubs and trees will restore habitat that has been avoided by LEPC and will create a release to allow for native grass and forb production. Conservation measures for brush management specify that implementation of the conservation practice within 0.5 miles of known leks will be deferred until breeding and nesting activities are completed, typically March 1 through July 15. The practice will be designed to create the desired habitat conditions for the LEPC. Treated sites may be deferred from livestock grazing, as deemed necessary. Brush management will help to address the issues of habitat loss and fragmentation.

- Benefits of Conservation Practices: Range Planting

  Range planting will benefit LEPC habitat and populations by restoring native habitats by converting cropland to grasslands to meet habitat requirements for LEPC. The goal is to restore the native plant community to a condition similar to the ecological site description reference state for the site, provide or improve forages for livestock, provide browse or cover for wildlife and reduce erosion by wind and/or water. Cropland sites typically provide inadequate food and cover for LEPC and other grassland species. Conservation measures for range planting specify that implementation of the conservation practice within 0.5 miles of known leks will typically be deferred until breeding and nesting activities are completed, typically March 1 through July 15, although planting may need to occur during this season. In these situations, an effort shall be made to complete these activities with as little disturbance as possible to adjacent and surrounding existing LEPC habitat. Range planting will create and improve habitat for LEPC, helping to address the issues of habitat loss and fragmentation.

- Benefits of offset unit generation (mitigation) with other NRCS practices: Other conservation practices may also be implemented on the mitigation property as appropriate and include practices that facilitate the implementation of the primary practices, such as a water development or fences to better manage grazed land, for example. These practices and their associated benefits and impacts to LEPC are discussed in Appendix B.

Remediation Activities

Oil and gas remediation and restoration include the removal of existing infrastructure (i.e., pump jacks, etc). Because these actions will occur within areas of existing impacts, we consider it less likely these areas will occupied by LEPC. Therefore, we did not expect many adverse effects from the implementation of remediation activities. In addition, the conservation measures such as the seasonal timing restrictions around leks still apply to these activities such that disturbances of breeding, lekking, or brooding birds will be minimized.

Evaluation of Potential Negative Effects of CCAA Relating to Habitat Loss

Although the implementation of the conservation measures would provide substantial benefits to the LEPC throughout the currently occupied range of the LEPC, we recognize that the proposed action would still allow for adverse effects to LEPC habitat, as described as follows:

- The avoidance measures specify that oil and gas development should avoid areas of high quality LEPC habitat (i.e., focal areas, connectivity areas, or areas within 1.25 miles of known leks) and, instead, should focus developments in areas with existing disturbances or lower quality habitat. However, if these conservation measures are not followed, oil and gas development would still be allowed to occur throughout the Action Area (EOR+10), including areas of higher quality habitat with the provision that offsetting mitigation is provided through the mitigation framework. The resulting consequences to the Participants for developing in areas of higher quality habitat would be that the Participants would be required to pay significantly higher mitigation fees than if the development occurred in lower quality habitat. In terms of impacts to LEPC, high quality habitat would be directly impacted if the habitat avoidance and minimization measures were not followed, although lekking, nesting, and brooding birds themselves would not be not be disturbed since development would not be allowed during the breeding season (March 1 – July 15) within 1.25 miles of leks that have been active in the last 5 years.

- The conservation measures provide for the minimization of impacts from oil and gas development through collocation of infrastructure, development in areas of existing disturbance, use of directional drilling, and clustering of facilities. However, if these conservation measures are not followed and habitat impacts were not minimized, oil

and gas development would still be allowed to occur with the resulting consequences to the Participants that they would be required to pay higher mitigation fees than if minimization measures were followed. In terms of impacts to LEPC, a greater area of surface disturbance would occur, likely resulting in habitat loss and fragmentation, if these habitat minimization measures were not followed.

- The discretionary nature of the avoidance and minimization measures allows for oil and gas development to occur in areas of high quality habitat. The potential loss of high quality habitat, especially lek sites, is of concern given the strong site fidelity of LEPC to leks (Copelin 1963, Hoffman 1963, Campbell 1972) and low dispersal distances (Braun et al. 1994). Jamison (2000) considered site fidelity to be more important than habitat in influencing the movements of male LEPC. Although the mitigation framework will provide for improved habitat or create new habitat offsite, the birds may not readily disperse and occupy the new or improved habitat.

- Once the conservation practices (e.g., prescribed grazing, prescribed burning, brush management, and range planting) are implemented, there may be a lag time between when the practice is implemented and when the conservation benefits are effectively available to the LEPC. Benefits from prescribed grazing are expected to be available rather quickly, likely starting within the year of implementation. Benefits from prescribed burning are also likely to be available rather quickly; the effects of prescribed burns were observed within 1- 3 years (Jamison 2000). Timing of availability of benefits from brush removal would probably take longer for the response of grasses and forbs and for the birds to reoccupy the area. No data were found describing the re-occupation of LEPC into areas of brush removal. The benefits of range planting will take longer before the site provides suitable habitat for LEPC, based on information from Conservation Reserve Projects (CRP) range planting. Seeding of native grasses in Kansas in areas of croplands can take 8-10 years before the grass has sufficient structure and cover to support LEPC (Rodgers and Hoffman 2005). In their design of the mitigation framework of the RWP, WAFWA has addressed the issue of a time lag between impacts units and offset units by ensuring that impacts are balanced with same quality or better quality by offset units annually within each focal area. Additionally, WAFWA has specified that contracts for the restoration projects (i.e., range planting and brush removal) will be for a minimum of 10 years, with the opportunity to extend those contracts at 5 year intervals, thereby allowing time for these conservation practices to provide for LEPC habitat.

- The conservation practice of range planting provides for the planting and establishment of native grasses, although it does not provide for the establishment of sand sagebrush and shinnery oak, which are important components in their respective ecoregions. We recognize, however, that seed mixes that contain tall bunch grasses will provide similar vegetative structure and cover for the LEPC.

- The avoidance measure specifies that oil and gas activities should avoid leks by 1.25 miles. Pitman et al. (2006) found that 80 percent of LEPC nesting activity occurs within 0.6 miles (1 km) of a lek. Giesen (1998) reported that hens usually nest within 1.7 miles (3.4 km) of nests and others have identified nesting occurring within 2 miles of leks. The potential remains for oil and gas development that occurs in the area between 1.25 miles and 2 miles of leks to result in the loss of nesting habitat and the disturbance and abandonment of birds in these areas, although the Service recognizes that the majority of the nesting habitat around active leks will be protected from habitat loss.

- Although the minimization conservation measures will reduce habitat loss and fragmentation impacts from oil and gas development by collocating and clustering infrastructure, the RWP does not provide specific guidance for maintenance of suitable habitat patch size (except for a minimum size of 160 acres for offset generation contracts). Therefore, there is no specific guidance for addressing issues relating to habitat fragmentation. However, several items within the RWP do help provide for issues of habitat fragmentation, including the prioritization of mitigation projects within the focal areas and connectivity areas and the development of strongholds (minimum of 25,000 acres) in each ecoregion.

- The Waiver Period during the first year of the implementation of the CCAA would allow for impact activities to occur prior to the establishment of offset units, potentially resulting in an imbalance of impacts units versus offset units and overall loss of habitat during this first year of the CCAA. The Service is concerned about the potential of a year of unmitigated impacts combined with other ongoing impacts, the potential continuation of drought in large areas of the LEPC range, and potential continuing decline of LEPC population numbers. The strategy developed by the Service and WAFWA will allow for limiting the amount of unmitigated development during the first year of the CCAA if the 2014 annual surveys indicate the population has dropped by 20 percent or more from the 2013 surveys (14,092 birds or less), with the provision that additional development can occur following adequate establishment of offset units (see description in *Proposed Action* section). This limited development during the first year of the CCAA is anticipated to limit the potential impacts from habitat loss and help provide for maintenance of the population.

- Another concern is that oil and gas development may occur on the mitigation property (i.e., offset unit) if there is a split estate situation in which the subsurface mineral rights are owned independently of the surface rights. This scenario applies to short-term contracts, permanent easements, and strongholds. The impact of development in permanent easements and strongholds would be to reduce the effect benefits of these areas through increasing habitat fragmentation. If a Participant were to develop land that is already in an offset unit contract, the Participant would be required to pay substantial mitigation fees both for the high quality habitat and for

reimbursement of the conservation practices, which may serve as a sufficient detriment to development at that site.

Impact Type: (II) Impacts Relating to Potential for Mortality and Injury of LEPC

Evaluations of expected beneficial effects to LEPC relating to mortality and injury

The conservation measures relating to collisions and other sources of mortality (including accidents and predation) will benefit the LEPC, as described in the following text:

- The avoidance conservation measures specify that distribution lines should be buried within 1.25 miles of leks active in the previous 5 years. Collisions with overhead transmission lines cause direct mortality to LEPCs and may further limit LEPC populations (Bidwell et al. 2003). Pittman (2006) observed that 80 percent of the females nested within 0.6 miles of a lek site. Transmission lines also provide perches for raptors, which could potentially increase the mortality rate of LEPCs (Bidwell et al. 2003). This measure will benefit the breeding birds and the marjority of the nesting birds by removing a collision risk within the vicinity of the active leks.

- The avoidance conservation measures also specify that appropriate fence markings will be installed along new fences within 0.25 miles of leks that have been active in the previous 5 years. LEPC mortalities have been documented from collision with fences This measure will benefit the breeding birds and the marjority of the nesting birds by reducing the collision risk within 0.25 miles of an active lek.

- The avoidance conservation measure specifies that new roads, fences, power lines, well pads, flowlines and other infrastructure should be located outside focal areas, connectivity zones, and high probability lek and nest habitat (2013 CHAT categories 1-3); this measure will further reduce collision risks with infrastructure. The minimization conservation measures that concentrates infrastructure, by specifying that common rights-of-way should be used and consolidating drilling operations and facilities, will also reduce the collision risks with infrastructure. The use of mono-pole construction for new electrical transmission lines in CHAT categories 1-3 will also reduce the risk for collisions by concentrating infrastructure.

- Mortalities associated with vehicles will be minimized by the conservation measure that requires a minimized traffic volume, a controlled vehicle speed, controlled access, and avoids off-road travel within focal areas and areas identified as high probability lek habitat by the 2013 CHAT.

- Mortalities associated with predation by raptors will be reduced by the recommendation of installing raptor determents on new electrical poles, as indicated by the Avian Power Line Interaction Committee (APLIC).

- Mortalities associated with drowning in human-made water containment sources will be minimized by the requirement to provide escape ramps, rafts, or ladders.

- As prescribed in the adaptive management table (provided in Appendix C), a number of mitigation-related elements in the adaptive management strategy provide for the evaluation of mortality and injury issues and for the adjustment of the CCAA operations, as appropriate. The element of emerging science relating to conservation practices for the LEPC and the CCAA will be evaluated annually.

Evaluations of Potential Negative Effects to the LEPC relating to Mortality

- The avoidance measure specifies specify that distribution lines should be buried within 1.25 miles of leks active in the previous 5 years. Pitman et al. (2006) found that 80 percent of LEPC nesting activity occurs within 0.6 miles (1 km) of a lek. Giesen (1998) reported that hens usually nest within 1.7 miles (3.4 km) of nests and others have identified nesting occurring within 2 miles of leks (Suminski 1977, Riley 1978, Giesen 1994a, p. 97). The potential remains for risk of collision with transmission lines that are not buried in the area between 1.25 miles and 2 miles of leks, although the Service recognizes that the collision risk has been reduced for the majority of the nesting habitat around active leks.

- While the avoidance conservation measures that directs that appropriate fence markings will be installed along new fences within 0.25 miles of active leks will minimize the collision risk around leks, the potential remains for collision risk with unmarked fences in the area between 0.25 miles and 2 miles from active leks.

Effect Type III: Impacts Relating to Disturbance of LEPC

Expected Beneficial Effects to the LEPC resulting from Implementation of CCAA

- Seasonal use restrictions within the plan are designed to minimize the take related to those actions and any other Covered Activities during key breeding, nesting and brooding periods. Those seasonal use restrictions are focused within 1.25 miles of known leks that have been recorded as active at least once within the previous five years. A perfect census of all leks across the plan area is not possible due to survey effort limitations and the fact that, by their nature, leks are not permanent fixtures on the landscape. . These seasonal use restrictions during the breeding, nesting, and brooding period will help to maintain and improve LEPC population number by reducing disturbances that could otherwise interfere with breeding activities and could reduce nesting and chick rearing success.

- The year-round noise abatement policy within 1.25 miles of active leks will further reduce the disturbances of birds in these areas and should provide for lek attendance

as birds will be better able to hear and respond to auditory cues at the lek sites. Noise associated with oil field activities may impact breeding activities if mating display vocalizations are disrupted by background noise (Davis 2006). Braun et al. (2002) noted that sage-grouse lek attendance was lower on breeding grounds located in close proximity to active mineral resource developments compared to less disturbed lek sites. Braun (1986) speculated that if noises associated with oil field activity deter recruitment of yearling sage-grouse males to breeding grounds, leks may become extinct.

- For those non-emergency operations, construction and maintenance activities that cannot avoid the area within 1.25 miles of active leks during March 1 through July 15, the conservation measures require a daily timing restriction (3:00 am to 9:00 am). This requirement will reduce disturbances to breeding birds present at the lek sites and their vicinity.

- The requirement for seismic activities and other similar activities to avoid extensive off road travel in rangeland or planted grass cover within 1.25 miles of active leks from March 1 through July 15 will further reduce disturbances of breeding, nesting, and brooding birds. The requirement for surveys to be conducted in CHAT 1-3 areas prior to breeding season seismic activities provides a substantial benefit to the implementation of this conservation measure.

- As prescribed in the adaptive management table (provided in Appendix C), a number of mitigation-related elements in the adaptive management strategy provide for the evaluation of mortality and injury issues and for the adjustment of the CCAA operations, as appropriate. The element of emerging science relating to conservation practices for the LEPC and the CCAA will be evaluated annually.

Evaluation of Potential Negative Effects of CCAA Relating to Disturbance of LEPC

- The conservation measures will overall reduce the disturbances of breeding, nesting and brooding birds but a number of exceptions will still allow for disturbances during this time. These exceptions include non-emergency operations, construction and maintenance activities that need to occur at this time. Although these activities will be required to avoid the time from 3:00 am to 9:00 am in the vicinity of active leks during the breeding season, thus reducing the disturbance of breeding activities, the potential remains for these activities to disturb and harm breeding and brooding bird in these areas. Furthermore, there is not a clear description from WAFWA of the criteria for actions that "cannot be avoided and must occur during March 1 – July 15" nor is there a requirement to coordinate this activity with WAFWA, potentially resulting in non-emergency, construction and maintenance operations occurring in the vicinity of active leks during the breeding season.

- On a case-by-case basis, some seismic activities with off road travel will be allowed within the period from March 1 – July 15 within 1.25 miles of active leks. This action could result in disturbances to LEPC, although this action will be evaluated and considered by WAFWA and should in conditions that would result in fewer impacts and would not occur during the time from 3:00 am to 9:00 am.

- The mitigation framework does not provide any mitigation of impacts resulting from disturbance effects.

Effects to LEPC from Implementation of Conservation Measures and Conservation Practices

Incidental take in the form of harm or harassment may result from disturbance incidental to the implementation of the Conservation Measures, including conservation practices (i.e., mitigation activities) required to offset impacts. Direct take, in the form of incidental killing of adults, juveniles, chicks, or eggs, also may result from the implementation of conservation measures and mitigation activities such as brush management practices, prescribed fire and grazing, and range planting. Some negligible disturbance is also possible from habitat monitoring activities. The following text describes potential impacts that could result from the conservation practices, as provided in Service's conference opinion for NRCS's Lesser Prairie-Chicken Initiative (LPCI) (NRCS 2013).

- *Prescribed grazing* is a widely used management practice to improve the quality of forage for livestock, and when applied through LPCI to improve rangeland vegetation to meet the habitat needs of LEPC. Pitman et al (2005) documented 4 of 209 nests were lost to trampling by cattle. Some but not all of the items in a grazing management plan are rest and deferment periods, stocking rates, location of mineral/salt supplements, and consideration of riparian and other sensitive or high impact areas. As a result of the expected implementation of the Prescribed Grazing system (528) guided by the 645 standard and as conditioned by the other conservation measures, the Service does not anticipate incidental take coverage is needed for any potential sources of adverse effects noted in the above analysis except for those related to livestock trampling.

- *Prescribed burning* is often used in conjunction with brush management but may also be used as a stand-alone tool for improving rangeland conditions. The potential disturbance associated with this practice is the destruction of nests if the fire is conducted during the nesting season. There are no empirical data on prescribed fire causing nest loss in LEPC, but Augustine and Sandercock (2011) documented 2 of 34 greater prairie-chicken nests were lost to prescribed fires in the Flint Hills of Kansas.

- *Range planting* is applied to restore the native plant community to a condition similar to the ecological site description reference state for the site, provide or improve forages for livestock and browse or cover for wildlife, reduce erosion by wind and/or

water, improve water quality and quantity, and increase carbon sequestration. This practice is used to restore important native habitats by converting cropland to grasslands, to meet habitat requirements for LEPC. As with brush management, the Service anticipates that incidental take estimates for range planting actions are based on the practices with largest potential disturbance (destroying nests and/or incubating hens), use of heavy machinery. Thus, it is likely overestimating incidental take. There are no empirical data estimating this type of nest or female loss. However, Pitman (2003) documented 1 female (of 209 nests) LEPC having been killed by farm machinery cutting the alfalfa field where she had nested. We believe similar rates of incidental take for the range planting practice can be expected.

- *Brush management* is a tool designed to remove or reduce woody species from prairie or grassland sites, primarily focused on eastern red cedar, honey mesquite, and in limited cases thinning of shinnery oak. Practices vary depending on the goal of the producer and needs of the species but include hand felling with chain saws as well as the use of small to large tractors with special shearing devices. In the limited case of herbicide treatment for shinnery oak thinning, there is specific guidance to maintain the integrity of the habitat for LEPCs. Incidental take estimates are based on the practices with largest potential disturbance (destroying nests and/or incubating hens), use of heavy machinery. Thus, it is likely overestimating incidental take. There are no empirical data estimating this type of nest or female loss. However, Pitman (2003) documented 1 female (of 209 nests) LEPC having been killed by farm machinery cutting the alfalfa field where she had nested.

Overall, the Service anticipates that incidental take from the implementation of the conservation measures, including the conservation practices (i.e., mitigation) will likely occur sporadically, and is not expected to nullify the high conservation benefit anticipated to accrue from implementation of the conservation practices and conservation measures in the CCAA. . In an effort to quantify this incidental take, we used the October 4, 2013 letter from WAFWA to the Service, in which WAFWA estimates that it could deliver, on average, 305,886 acres of conservation per year (WAFWA 2013b, pg. 2). We also used NRCS's estimate from its LPCI conference opinion that anticipates that one bird for every 4,000 acres treated would be incidentally taken annually (NRCS 2013). Based on these values, we estimate that the conservation practices utilized for the mitigation framework could result in the incidental take of approximately 76 birds annually (305,886 ac/4,000 ac = 76 birds). The Service understands that the minimal incidental take resulting from these activities will be provided by a separate permit or rule through the RWP.

Summary of Effects

The RWP's conservation strategy is designed to provide a net long-term benefit to the LEPC through a combination of conservation measures, mitigation framework, and an adaptive management strategy. The RWP identifies a desired population goal of an average of 67,000

birds in the first 10 years of the RWP within the EOR+10. Additional population and habitat goals are provided in the RWP that collectively work to support this overall population goal.

Conservation Measures – Development of well pads, compressor stations, roads, transmission lines, etc., can result in LEPC habitat loss and fragmentation throughout the Covered Area. The conservation measures will provide incentives to avoid and minimize impacts to LEPC habitat, especially in the high priority areas (i.e., focal areas and connectivity areas) through the use of higher mitigation fees in these areas. Restrictions on development impacts in focal areas and connectivity zones (i.e., no more than 30 and 60 percent development impacts, respectively) will further provide for the maintenance of habitat in CHAT 1 and 2 categories.

Conservation measures also provide for the avoidance and minimization of impacts to birds during the breeding season as well as for the reduction in risks of mortality and injury to LEPC. Oil and gas operations will avoid the area within 1.25 miles of active leks (i.e., active within previous 5 years) during the breeding season, with some exceptions for emergency and other actions that need to occur. Seismic activities involving off-road travel shall not be conducted in rangeland or grassland within 1.25 miles of active leks during the breeding season, with some exceptions, and surveys will be required in CHAT categories 1-3 prior to breeding season seismic activities. These measures, and a requirement for providing year-round noise abatement within 1.25 miles of active leks, will greatly reduce disturbances to birds during the breeding season. The risks of mortality and injury to LEPC will be reduced by additional measures that require the burying of new distribution lines within 1.25 miles of active leks, installing fence markers with 0.25 miles of active leks, escape ramps in water tanks, as well as other measures. The avoidance and minimization conservation measures are expected to reduce the effects on population numbers and distribution resulting from oil and gas activities.

Mitigation - Project mitigation will be provided by implementation of NRCS conservation practices that are designed to provide food, shelter, and cover for LEPC. Mitigation will occur at a 2:1 mitigation to impact ratio and is designed to provide a permanent offset of impacts in perpetuity through a non-wasting endowment. Offset units will include 25 percent in permanent easements and strongholds and 75 percent in term contracts (5-10 years). Private landowners will be compensated for mitigation on enrolled land. Mitigation practices also include remediation of existing infrastructure in the Covered Area. The mitigation conservation measures are expected to benefit LEPC population numbers, reproduction, and distribution as a result of implementation of conservation practices that are funded through migitation fees paid by the Participants.

Adaptive Management - The CCAA will utilize adaptive management strategies to allow for mutually agreed-upon changes to practices to occur in response to changing conditions or new information, including those identified during monitoring, that may be necessary to reach the stated short term and long-term goals. Some of the factors that will be evaluated regularly by the various committees include LEPC population sizes, progress toward habitat

goals, conservation practice costs, avoidance of high priority conservation areas, management prescriptions, etc. The adaptive management strategies in the CCAA are expected to benefit the LEPC and its habitat by providing timely adjustments to practices to better meet the habitat and populations goals stated in the RWP.

Summary - The benefits provided by the combination of the conservation measures, mitigation framework, and adaptive management will result in focal areas and connectivity zones that will have reduced threats and disturbances to LEPC, and improved habitat that is concentrated in larger blocks of contiguous habitat. These conditions are expected to 1) result in an increase in LEPC populations throughout the currently occupied range, 2) maintain and expand the current distribution of the LEPC across its estimated occupied range, and 3) increase population numbers that will result in more sustainable long-term populations within each of the four delineated ecoregions.

CUMULATIVE EFFECTS

Cumulative effects include the effects of future state, tribal, local or private actions that are reasonably certain to occur in the action area considered in this biological opinion. Future Federal actions that are unrelated to the proposed action are not considered in this section because those actions require separate consultation pursuant to section 7 of the Act.

The action area consists primarily of private and State lands interspersed with the public land. Unregulated activities on state and private lands such as livestock grazing, inappropriate use of OHVs, agricultural development, residential or commercial development, alternative energy and oil and gas development, conversion of CRP lands to croplands, non-native plant invasion, and inappropriate herbicide application may adversely affect the LEPC through a variety of avenues. Many of these threats may exacerbate the normal effects of periodic drought on LEPC populations.

Within the action area are a number of state, Federal, and private programs that currently provide conservation benefits to the species and directly address threats to the LEPC. These programs provide technical and financial assistance to landowners for habitat management for LEPC. Several programs address industry siting, best management practices, and avoidance, minimization and voluntary mitigation. Additional programs provide for direct management of LEPC habitat on public or other lands within LEPC range, including CRP through the FSA and grazing and ranching operations through the NRCS. Collectively, these existing conservation programs provide a net conservation benefit to the LEPC.

CONCLUSION

After reviewing the current status of the LEPC, the environmental baseline for the action area, the positive and negative effects of the proposed action, and the cumulative effects, it is

the Service's biological opinion that the action, as proposed, is not likely to jeopardize the continued existence of the LEPC. We anticipate that the implementation of the proposed action will not appreciably diminish the likelihood of both the survival and recovery of the LEPC. In fact, the Service expects the overall effect of the proposed action to result in a larger amount of suitable habitat and protection of important habitat, resulting in an improvement in LEPC numbers, distribution, and reproduction. No critical habitat has been designated for the species; therefore, none will be affected. We base this conclusion on the following:

- Implementation of the avoidance and minimization conservation measures contained within the CCAA will benefit the LEPC throughout its currently occupied range by reducing the impacts to high quality habitat, by reducing the risks of collision and other causes of mortality, and by reducing disturbances to breeding, nesting, and brooding LEPC from new oil and gas development.
- These avoidance and minimization measures are expected to enhance the survival of the LEPC throughout its currently occupied range (approximately 40 million acres), which includes Kansas, Colorado, New Mexico, Oklahoma, and Texas.
- This reduction in threats will be focused in the higher priority areas (e.g., focal areas and connectivity zones) through an impact fee structure that encourages conservation of higher quality habitat through higher mitigation fees in the priority areas and, through lower mitigation fees in lower priority areas of the Covered Area. The reduction of threats to habitat and birds, especially in high priority areas, is anticipated to result in improved habitat and increased population numbers.
- The mitigation conservation measures will enhance the recovery of the LEPC through implementation of conservation practices that improve habitat quality through prescribed grazing, prescribed burning, range planting, and brush management. These practices will improve LEPC habitat through increased vegetation cover, nesting and thermal cover, and foraging material and are expected to result in increased population numbers.
- The mitigation will be focused in the high priority areas, namely the focal areas and the connectivity zones, which will provide for the restoration, enhancement, and maintenance of large, contiguous blocks of habitat needed by LEPC and will minimize habitat fragmentation.
- Mitigation will occur at a 2:1 ratio of mitigation to impacts. Impacts will be mitigated in perpetuity through the payment of mitigation fees into a non-wasting endowment.
- The adaptive management strategy provides for the monitoring and evaluation of habitat and population conditions, and for the adjustment of the CCAA operations, as appropriate. Some of the factors that will be evaluated regularly by the various committees include LEPC population sizes, progress toward habitat goals, emerging science, conservation practice costs, avoidance of high priority conservation areas, management prescriptions, etc.

- The CCAA will complement the existing conservation efforts of other state, Federal, and private programs that provide conservation benefits to the species and directly address threats to the LEPC, thus resulting in a landscape level conservation that is expected to result in improved population numbers and re-establishment and recolonization of habitats by LEPC.

INCIDENTAL TAKE STATEMENT

Section 9 of the Act and Federal regulation pursuant to section 4(d) of the Act prohibit the take of endangered and threatened species, respectively, without special exemption. Take is defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or to attempt to engage in any such conduct. Harm is further defined by the Service to include significant habitat modification or degradation that results in death or injury to listed species by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering. Harass is defined by the Service as an intentional or negligent act or omission which creates the likelihood of injury to wildlife by annoying it to such an extent as to significantly disrupt normal behavior patterns which include, but are not limited to, breeding, feeding or sheltering. Incidental take is defined as take that is incidental to, and not the purpose of, the carrying out of an otherwise lawful activity. Under the terms of section 7(b)(4) and section 7(o)(2), taking that is incidental to and not intended as part of the agency action is not considered to be prohibited taking under the Act provided that such taking is in compliance with the terms and conditions of this incidental take statement.

Evaluation of Incidental Take

The proposed CCAA for the LEPC throughout its occupied range in five states includes a suite of conservation measures to reduce impacts from oil and gas activities activities. Implementation of these measures will result in minimizing the degree and amount of those impacts on the LEPC. However, the actions considered in the CCAA are still likely to result in some incidental take of LEPC.

The Service anticipates that the incidental take of LEPC will be difficult to determine for the following reasons: 1) the uncertainty of population numbers, 2) the minimal likelihood of finding a dead or impaired specimen, and 3) because losses may be masked by seasonal fluctuations in environmental conditions and natural fluctuations in population numbers. Therefore, it is difficult to provide precise numbers of LEPCs that will be harassed, harmed, or killed as a result of the proposed action. In such instances where take of individuals is difficult to detect and/or quantify, take may be quantified in terms of an aspect of the species' habitat that may be diminished or removed by the action. Given the large scale of the proposed action, the fluctuations in oil and gas prices and the resulting changes in the extent of oil and gas development that may occur over the next 30 years, and fluctuations occurring within LEPC population numbers, the Service recognizes there is a level of uncertainty inherent to making an estimate of incidental take for this proposed action.

Amount or Extent of Anticipated Take

For our estimate of incidental take for the 30 years of the implementation of the CCAA, we utilized WAFWA's estimates of impacted acres and the birds potentially taken, as provided in Table 6. We then reduced those values by using WAFWA's estimate of reduced surface disturbance (58 percent reduction) due to the use of overlap with existing infrastructure and rights-of-way that is estimated to occur by WAFWA through the implementation of the conservation measures in the CCAA. Additionally, we added the estimated incidental take resulting from implementation of the conservation practices. Our estimates are provided in Table 7.

Based on the information shown in Table 7, the Service is anticipating incidental take for 30 years implementation of the CCAA for a total of 8,530 birds for the 30-year life of the CCAA. Because of the difficulty in detecting birds, this incidental take will be measured in terms of the acreage impacted by project activities.

Therefore, the Service considers that incidental take of LEPC will be exceeded if any of the conditions are met:

1) At 10 years of implementation of the CCAA, more than 622,272 acres are developed by oil and gas activities within the Covered Area;
2) At 20 years of implementation of the CCAA, more than 1,244,545 acres are developed by oil and gas activities within the Covered Area;
3) At 30 years of implementation of the CCAA, more than 1,866,855 acres are developed by oil and gas activities within the Covered Area.

Effect of the Take

In the accompanying opinion, we have determined that the level of adverse effects rising to the level of anticipated take is not likely to jeopardize the continued existence of the LEPC. Although we anticipate that incidental take to occur, the implementation of the conservation measures should ultimately result in an overall increase of habitat and presumably the number of LEPC in the long term.

REASONABLE AND PRUDENT MEASURES AND TERMS AND CONDITIONS

All conservation measures, including avoidance, minimizations, and mitigation of LEPC habitats, status surveys, biological and compliance monitoring, and reporting measures are considered commitments from the permittee and are part of the proposed action. Deviation from those commitments may trigger the need to reinitiate consultation.

The Service has no reasonable and prudent measures or implementing terms and conditions to minimize the effects of take on the species. The incidental take coverage for LEPC

covered by the CCAA and the section 10(a)(1)(A) permit will become effective upon the listing of these species as threatened or endangered under the Act.

Conservation Recommendations

1. The Service encourages Participants to participate in annual meetings with the WAFWA, Service, and other participating landowners to discuss progress in recovery of LEPCs on participating lands.
2. The Service encourages Participants to contribute information to an annual progress report about range conditions, land management activities, LEPC abundance and distribution, and factors that may be having positive and negative effects on LEPC populations, in addition to those reporting requirements in the CCAA.
3. The Service encourages landowners to maintain enrollment in the Conservation Reserve Program.
4. The Service encourages Participants and other landowners to allow removal of legacy oil and gas wells and infrastructure, and restoration of LEPC habitat.
5. The Service encourages research on LEPC for items identified as Research Needs, as provided in the CCAA.

REINITIATION NOTICE

This concludes the conference for the issuance of an section 10(a)(1)(A) enhancement of survival permit associated with the CCAA for the LEPC. If the species becomes listed and the Service reviews the proposed action and finds that there have been no significant changes in the action as planned or in the information used during the conference, the Service may adopt this conference as a final biological opinion.

After any future listing of the LEPC as threatened or endangered and any subsequent adoption of this conference opinion, consultation must be reinitiated if: (1) the amount or extent of incidental take is exceeded; (2) new information reveals effects of the proposed action that may affect listed species or critical habitat in a manner not considered in this conference opinion, including a substantial decline in the population trend or if the identified population or habitat goals have not been achieved, following sufficient application of the adaptive management strategy; (3) the proposed action is subsequently modified in a manner that causes an effect to listed species not considered in this conference opinion; or (4) a new species is listed or critical habitat designated that may be affected by the proposed action.

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Appendix A. Oil and Gas Activities Addressed in the CCAA

Oil and gas development-related activities that have the potential to cause specific threats to LEPC would be covered by the permit (Covered Activities). The implementation of associated conservation measures (see *Conservation Measures* below) on Enrolled Properties is also considered a Covered Activity. These activities, which span the entire life-cycle of oil and gas development operations, generally include, but are not limited to, the following.

Seismic and Land Surveying

Seismic activities are generally performed in the exploration mode of oil and gas development or in areas of development for refining knowledge of the geology and improving well siting. Seismic activities are conducted for short periods (i.e., days) in any given area. Activities may include the use of large equipment to induce seismic pulses. Additionally, activities may include limited clearing of vegetation to allow equipment access for seismic work, which could consist of a small crew laying/stringing temporary cables and placing receivers on foot or possibly using off-highway vehicles (OHVs). A crew would remove the cables when the project is complete. Land surveying is a temporary activity and may require some truck and/or foot traffic.

Construction

Construction of facility sites and associated infrastructure, which includes, but is not limited to, access roads, well pads or locations, reserve pits, and other facilities for the disposal of waste, tanks and storage facilities, treaters, separators, dehydrators, electric and other utility lines, and pipelines (e.g., gathering lines, flowlines, and distribution lines) may include the use of heavy equipment and trucking activities in clearing vegetation, contouring, compacting, stabilizing soils, and installing erosion control (including silt fencing, earthen berms, etc., per Clean Water Act permitting requirements). Well site construction may also include erecting temporary fencing and netting around a location, or portions thereof, for livestock and wildlife protection. A water well, disposal well, and/or injection well may be drilled near the location and possible trenching-related activities associated with installation of flowlines, pipelines, and utilities may occur. Associated infrastructure for compressor facilities and gathering/processing facilities may also be constructed on-site or at adjacent sites. Where practical, equipment may be electrified (greatly reducing noise and emissions from gas-driven equipment), which involves the installation of in-field electrical distribution systems (poles, transformers, and overhead wires).

Drilling, Completion, and Workovers (Recompletion)
Related drilling, completion, and workover activities include rig mobilization and can include heavy equipment and frequent traffic. Wellbore completion activities, such as hydraulic fracturing, would not directly impact the LEPC because these activities are contained and take place on the well site location. Well site fencing may be used after recompletion operations for security and to limit access.

Routine Operations and Maintenance
Routine operations can include stimulations and wellbore repair, daily inspections and maintenance, gathering line and flowline repairs, unloading storage tanks, truck traffic for removal of product or waste, emergency response activities, workovers, recompletions, flaring, and weed control.

Oil and Gas Remediation and Restoration
Remediation and restoration of surface impacts include, but are not limited to, removal and restoration of access roads; well pads or locations; reserve pits and other facilities for the disposal of waste; tanks and storage facilities; treaters; separators; dehydrators; electric and other utility lines and pipelines (e.g., gathering lines, flowlines, and distribution lines); associated infrastructure for compressor facilities; and gathering/processing facilities. Remediation and restoration may occur on any lands within the Covered Area, but such lands need not be enrolled in a CI under this Range-wide Oil and Gas CCAA or in the RWP.

Appendix B. Conservation Practices

Table 1. Conservation Practices by Names, Numbers, and Definitions (Van Pelt et al. 2013, p. 150-151)

Conservation Practice Name	Conservation Practice Number	Conservation Practice Definition
Upland Wildlife Habitat Management	645	Provide and manage upland habitats and connectivity within the landscape for wildlife.
Prescribed Grazing	528	Managing the harvest of vegetation with grazing and/or browsing animals.
Restoration and Management of Rare and Declining Habitats	643	Restoring, conserving, and managing unique or diminishing native terrestrial and aquatic ecosystems
Access Control	472	The temporary or permanent exclusion of animals, people, vehicles, and/or equipment from an area
Forage Harvest Management	511	The timely cutting and removal of forages from the field as hay, green-chop or ensilage
Prescribed Burning	338	Controlled fire applied to a predetermined area
Brush Management	314	The management or removal of woody (non-herbaceous or succulent) plants including those that are invasive and noxious
Firebreak	394	A permanent or temporary strip of bare or vegetated land planned to retard fire
Cover Crop	340	Crops including grasses, legumes, and forbs for seasonal cover and other conservation purposes
Critical Area Planting	342	Establishing permanent vegetation on sites that have, or are expected to have, high erosion rates, and on sites that have physical, chemical or biological conditions that prevent the establishment of vegetation with normal practices
Forage and Biomass Planting	512	Establishing adapted and/or compatible species, varieties, or cultivars of herbaceous species suitable for pasture, hay, or biomass production
Range Planting	550	Establishment of adapted perennial or self-sustaining vegetation such as grasses, forbs, legumes, shrubs and trees.
Watering Facility	614	A permanent or portable device to provide an adequate amount and quality of drinking water for livestock and/or wildlife

Spring Development	574	Collection of water from springs or seeps to provide water for a conservation need
Pumping Plant	533	A facility that delivers water at a designed pressure and flow rate. Includes the required pump(s), associated power unit(s), plumbing, appurtenances, and may include on-site fuel or energy source(s), and protective structures
Water well	642	A hole drilled, dug, driven, bored, jetted or otherwise constructed to an aquifer for water supply
Pipeline	516	Pipeline having an inside diameter of 8 inches or less
Grade Stabilization Structure	410	A structure used to control the grade and head cutting in natural or artificial channels
Fence	382	A constructed barrier to animals or people
Obstruction Removal	500	Removal and disposal of buildings, structures, other works of improvement, vegetation, debris or other materials
Herbaceous Weed Control	315	The removal or control of herbaceous weeds including invasive, noxious and prohibited plants
Pond	378	A water impoundment made by constructing an embankment or by excavating a pit or dugout. In this standard, ponds constructed by the first method are referred to as embankment ponds, and those constructed by the second method are referred to as excavated ponds. Ponds constructed by both the excavation and the embankment methods are classified as embankment ponds if the depth of water impounded against the embankment at the auxiliary spillway elevation is 3 feet or more
Tree and Shrub Planting	612	Establishing woody plants by planting seedlings or cuttings, direct seeding, or natural regeneration
Heavy Use Protection	561	The stabilization of areas frequently and intensively used by people, animals, or vehicles by establishing vegetative cover, surfacing with suitable materials, and/or installing needed structures
Woody Residue Treatment	384	The treatment of residual woody material that is created due to management activities or natural disturbances
Well Decommissioning	351	The sealing and permanent closure of a water well no longer in use
Conservation Cover	327	Establishing and maintaining permanent vegetative cover

Appendix C. Adaptive Management

Table 1. Identified activities or situations that will trigger the adaptive management process or a specific conservation action.

Evaluated Element	Utilized Information	Trigger(s)	Evaluation Frequency	Primary Corrective Action(s) Considered	Spatial Scale	Anticipated Response
Administrative Fee	Stability of administrative endowment using figures contained within the WAFWA financial report	Balance in the administrative endowment is not being sustained	Annually	Administrative fee is increased from 12.5%	Range-wide	Administrative fee is increased to ensure a non-wasting endowment for administrative services
Individual technical service provider compliance	Reports submitted by technical service providers	Provider is not in full compliance WAFWA reporting standards	Annually	Issue non-compliance warning with corrective measures, removal of certification	Range-wide	Provider corrects error and comes into full compliance
Population size	3-year average breeding population estimates derived from aerial survey and population reconstruction (pre-2012)	3-year moving average less than 50% of population goal	Annually	A discussion would be triggered with the science team to identify the cause of the low population. Potential corrective actions that could be taken starting in 2016 would include reprioritization of conservation actions when evaluating landowner offers and adjustment of mitigation multipliers and ratios	Ecoregion and range-wide	Populations recover above 50% of goal and trajectory is sufficient for bird numbers to reach or exceed goals after 10 years of plan implementation
Conservation practice costs	USDA estimated practice costs	WAFWA practice cost figures differ from USDA estimated costs	Annually	Fee structure working group reviews practice costs and recommends changes if necessary	Ecoregion	WAFWA payment rates adjusted to correlate with USDA practice cost estimates
Emerging science	Peer-reviewed literature	New peer-reviewed articles pertaining to aspects of the conservation strategy, the mitigation framework, or conservation practices become available	Annually	Science team reviews materials and recommends changes if necessary	Ecoregion and range-wide	Conservation strategy, mitigation framework, and/or conservation practices modified to conform with the best available science. If required, amendment of the CCAA or CI will proceed as provided in Section ___

Evaluated Element	Utilized Information	Trigger(s)	Evaluation Frequency	Primary Corrective Action(s) Considered	Spatial Scale	Anticipated Response
Tangible mitigation unit offset ratio (not acreage)	Enrolled offset and impacts units presented in WAFWA affected acreage report	Observed offset and impact unit ratio differs from planned figure (initially 2:1)	Annually	Adjust offset ratios, increase landowner outreach efforts, adjust landowner sign-up schedule and associated allocation amounts	Ecoregion	Observed offset and impact unit ratio moves toward planned figure (initially 2:1)
Quality of offset acreage	HEG scores and affected acreages provided in WAFWA Affected Acreage Report	Average HEG score per acre of offset acreage < average HEG score of impacted acreage	Annually	Adjust offset ratios, adjust mitigation unit values, prioritize higher quality habitat when ranking landowner offers	Ecoregion	Quality on offset acreage is > quality of impacted acreage
Habitat Restoration Goals	Restoration acreages presented in WAFWA affected acreage report	Did not achieve the annual acreage goals for total restoration and remediation (see appendices D and E)	Annually	Adjust mitigation multipliers and ratios, increase prioritization of restoration practices when ranking landowner offers, increase assumption of 25% restoration when valuing mitigation units	Focal Area and Connectivity Zone Reporting Areas	Factors preventing maintenance at habitat goal or progress toward it are reduced or eliminated
Habitat Quantity	Occupancy model results and restoration acreages presented in WAFWA affected acreage report	Occupancy model results indicate that the amount of good to high quality habitat is below the goal for focal areas (70%) or connectivity zones (40%) or restoration and remediation has not occurred on half the required acreage (see appendices D and E)	5 Years	Shift reporting area locations, adjust mitigation multipliers and ratios, increase prioritization of restoration practices when ranking landowner offers, increase assumption of 25% restoration when valuing mitigation units	Focal Area and Connectivity Zone Reporting Areas	Factors preventing maintenance at habitat goal or progress toward it are reduced or eliminated
Sustainability of conservation offset endowment	Real rate of return on investments	The average real rate of return differs from 4%	5 Years	Multiplier adjusted	Range-wide	Endowment becomes non-wasting
Strongholds	Identified stronghold acreages provided in the WAFWA affected acreage report	Participation rate not on pace to achieve 10-year stronghold acreage goals	5 Years	Adjust percent of units going into permanent conservation, adjust offset ratios	Ecoregion	Participation in long-term conservation practices becomes sufficient to achieve 10-year acreage goals

Evaluated Element	Utilized Information	Trigger(s)	Evaluation Frequency	Primary Corrective Action(s) Considered	Spatial Scale	Anticipated Response
Conservation practices	WAFWA vegetation monitoring data presented in WAFWA affected acreage report	Optimum habitat not maintained in 3 of 5 years when it existed at baseline and was the desired outcome or vegetation structure not >25% improved over baseline when it was anticipated in the associated management plan	5 Years	Change conservation practice prescriptions	Ecoregion	Management prescriptions will be more likely to create vegetative structure that maximizes a sites LEPC habitat potential
Avoidance of high priority CHAT categories	Enrolled acreage presented in WAFWA Affected Acreage Report	Proportion of CHAT acreage affected by new impacts does not differ across categories	5 Years	Adjust offset ratios	Ecoregion	Proportionally less development begins to occur in higher priority CHAT categories
Population goal	Aerial survey breeding population estimates	10-year average population size less than stated goal	10 Years	Reallocate dollars across ecoregions, shift priority area locations, adjust offset ratios	Ecoregion	Limiting factor(s) reduced or eliminated so that conservation actions are sufficient to achieve population goal

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Abstract

Benefit–cost analysis can serve as an informative input into the policy-making process, but only to the degree it characterizes the major impacts of the regulation under consideration. Recently, the US, amongst other nations, has begun to use estimates of the social cost of CO_2 (SC-CO_2) to develop analyses that more fully capture the climate change impacts of GHG abatement. The SC-CO_2 represents the aggregate willingness to pay to avoid the damages associated with an additional tonne of CO_2 emissions. In comparison, the social costs of non-CO_2 GHGs have received little attention from researchers and policy analysts, despite their non-negligible climate impact. This article addresses this issue by developing a set of social cost estimates for two highly prevalent non-CO_2 GHGs, methane and nitrous oxide. By extending existing integrated assessment models, it is possible to develop a set of social cost estimates for these gases that are consistent with the SC-CO_2 estimates currently in use by the US federal government.**Policy relevance**Within the benefit–cost analyses that inform the design of major regulations, all Federal agencies within the US Government (USG) use a set of agreed upon SC-CO_2 estimates to value the impact of CO_2 emissions changes. However, the value of changes in non-CO_2 GHG emissions has not been included in USG policy analysis to date. This article addresses that omission by developing a set of social cost estimates for two highly prevalent non-CO_2 GHGs, methane and nitrous oxide. These new estimates are designed to be compatible with the USG SC-CO_2 estimates currently in use and may therefore be directly applied to value emissions changes for these non-CO_2 gases within the benefit–cost analyses used to evaluate future policies.

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Keywords

- integrated assessment,
- non-CO_2 GHGs,
- social cost of carbon

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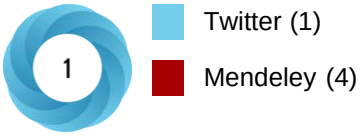
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LETTERS

Greenhouse-gas emission targets for limiting global warming to 2 °C

Malte Meinshausen[1], Nicolai Meinshausen[2], William Hare[1,3], Sarah C. B. Raper[4], Katja Frieler[1], Reto Knutti[5], David J. Frame[6,7] & Myles R. Allen[7]

More than 100 countries have adopted a global warming limit of 2 °C or below (relative to pre-industrial levels) as a guiding principle for mitigation efforts to reduce climate change risks, impacts and damages[1,2]. However, the greenhouse gas (GHG) emissions corresponding to a specified maximum warming are poorly known owing to uncertainties in the carbon cycle and the climate response. Here we provide a comprehensive probabilistic analysis aimed at quantifying GHG emission budgets for the 2000–50 period that would limit warming throughout the twenty-first century to below 2 °C, based on a combination of published distributions of climate system properties and observational constraints. We show that, for the chosen class of emission scenarios, both cumulative emissions up to 2050 and emission levels in 2050 are robust indicators of the probability that twenty-first century warming will not exceed 2 °C relative to pre-industrial temperatures. Limiting cumulative CO_2 emissions over 2000–50 to 1,000 Gt CO_2 yields a 25% probability of warming exceeding 2 °C—and a limit of 1,440 Gt CO_2 yields a 50% probability—given a representative estimate of the distribution of climate system properties. As known 2000–06 CO_2 emissions[3] were ~234 Gt CO_2, less than half the proven economically recoverable oil, gas and coal reserves[4–6] can still be emitted up to 2050 to achieve such a goal. Recent G8 Communiqués[7] envisage halved global GHG emissions by 2050, for which we estimate a 12–45% probability of exceeding 2 °C—assuming 1990 as emission base year and a range of published climate sensitivity distributions. Emissions levels in 2020 are a less robust indicator, but for the scenarios considered, the probability of exceeding 2 °C rises to 53–87% if global GHG emissions are still more than 25% above 2000 levels in 2020.

Determining probabilistic climate change for future emission scenarios is challenging, as it requires a synthesis of uncertainties along the cause–effect chain from emissions to temperatures; for example, uncertainties in the carbon cycle[8], radiative forcing and climate responses. Uncertainties in future climate projections can be quantified by constraining climate model parameters to reproduce historical observations of temperature[9], ocean heat uptake[10] and independent estimates of radiative forcing. By focusing on emission budgets (the cumulative emissions to stay below a certain warming level) and their probabilistic implications for the climate, we build on pioneering mitigation studies[11,12]. Previous probabilistic studies—while sometimes based on more complex models—either considered uncertainties only in a few forcing components[13], applied relatively simple likelihood estimators ignoring the correlation structure of the observational errors[14] or constrained only model parameters like climate sensitivity rather than allowed emissions.

Using a reduced complexity coupled carbon cycle–climate model[15,16], we constrain future climate projections, building on the Fourth IPCC Assessment Report (AR4) and more recent research. In particular, multiple uncertainties in the historical temperature observations[9] are treated separately for the first time; new ocean heat uptake estimates are incorporated[10]; a constraint on changes in effective climate sensitivity is introduced; and the most recent radiative forcing uncertainty estimates for individual forcing agents are considered[17].

The data constraints provide us with likelihood estimates for the chosen 82-dimensional space of climate response, gas-cycle and radiative forcing parameters (Supplementary Fig. 3). We chose a Bayesian approach, but also obtain 'frequentist' confidence intervals for climate sensitivity (68% interval, 2.3–4.5 °C; 90%, 2.1–7.1 °C), which is in approximate agreement with the recent AR4 estimates. Given the inherent subjectivity of Bayesian priors, we chose priors for climate sensitivity such that we obtain marginal posteriors identical to 19 published climate sensitivity distributions (Fig. 1a). These distributions are not all independent and not equally likely, and cannot be formally combined[18]. They are used here simply to represent the wide variety of modelling approaches, observational data and likelihood derivations used in previous studies, whose implications for an emission budget have not been analysed before. For illustrative purposes, we chose the climate sensitivity distribution of ref. 19 with a uniform prior in transient climate response (TCR, defined as the global-mean temperature change which occurs at the time of CO_2 doubling for the specific case of a 1% yr^{-1} increase of CO_2) as our default. This distribution closely resembles the AR4 estimate (best estimate, 3 °C; likely range, 2.0–4.5 °C) (Supplementary Information).

Maximal warming under low emission scenarios is more closely related to the TCR than to the climate sensitivity[19]. The distribution of the TCR of our climate model for the illustrative default is slightly lower than derived within another model set-up[19], but within the range of results of previous studies (Fig. 1b), and encompasses the range arising from emulations by coupled atmosphere–ocean general circulation models[16] (AOGCMs) (Fig. 1c).

Representing current knowledge on future carbon-cycle responses is difficult, and might be best encapsulated in the wide range of results from the process-based C4MIP carbon-cycle models[8]. We emulate these C4MIP models individually by calibrating 18 parameters in our carbon-cycle model[16], and combine these settings with the other gas cycles, radiative forcing and climate response parameter uncertainties gained from our historical constraining.

Additional challenges arise in estimating the maximum temperature change resulting from a certain amount of cumulative emissions. The analysis needs to be based on a multitude of emission pathways with realistic multi-gas characteristics[20,21], as well as varying

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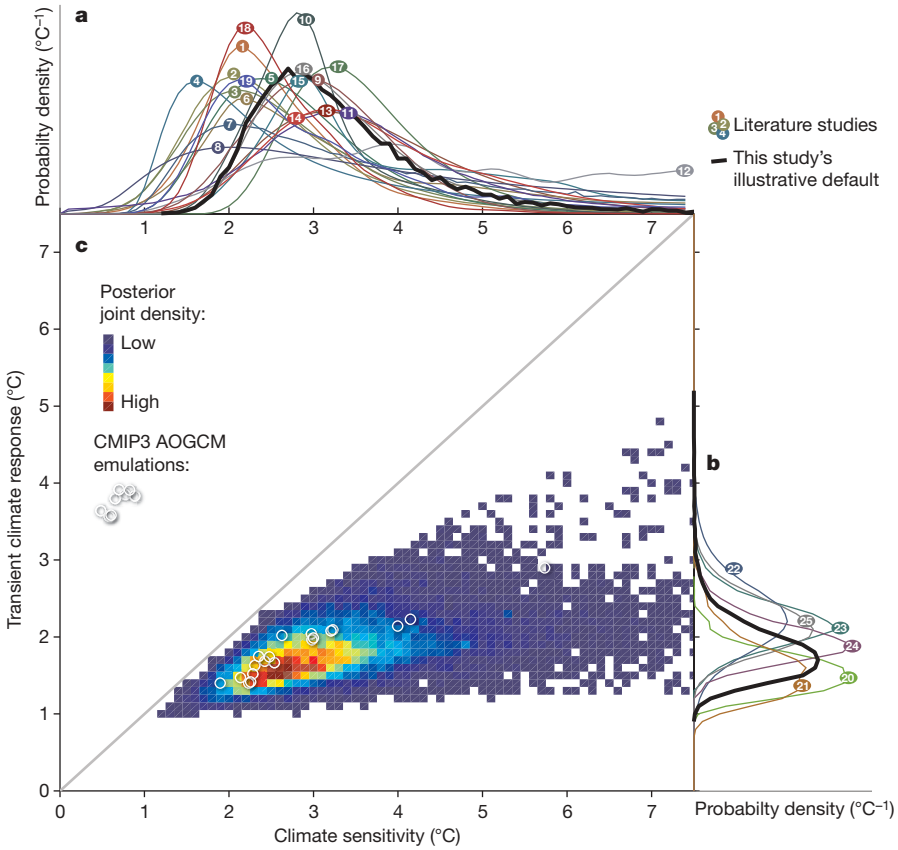


Figure 1 | Joint and marginal probability distributions of climate sensitivity and transient climate response. **a**, Marginal probability density functions (PDFs) of climate sensitivity; **b**, marginal PDFs of transient climate response (TCR); **c**, posterior joint distribution constraining model parameters to historical temperatures, ocean heat uptake and radiative forcing under our representative illustrative priors. For comparison, TCR and climate sensitivities are shown in **c** for model versions that yield a close emulation of 19 CMIP3 AOGCMs (white circles)[16]. Data sources for curves 1–25 are given in Supplementary Information.

shapes over time. AOGCM results for multi-gas mitigation scenarios were not available for assessment in the IPCC AR4 Working Group I Report[22]. Consequently, IPCC AR4 Working Group III[23] provided equilibrium warming estimates corresponding to 2100 radiative forcing levels for some multi-gas mitigation scenarios, using simplified regressions (Supplementary Fig. 6). Thus, 15 years after the first pioneering mitigation studies[11,12], there is still an important gap in the literature relating emission budgets for lower emission profiles to the probability of exceeding maximal warming levels; a gap that this study intends to fill.

We compute time-evolving distributions of radiative forcing and surface air temperature implications for the set of 26 IPCC SRES[21] and 20 EMF-21 scenarios[20] shown in Fig. 2a and b. We complement these with 948 multi-gas equal quantile walk emission pathways[24] that share—by design—similar multi-gas characteristics (Supplementary Fig. 5) but represent a wide variety of plausible shapes, ranging from early moderate reductions to later peaking and rapidly declining emissions towards near-zero emissions (Supplementary Information). Whereas Fig. 2e shows a standard plot of global-mean temperature versus time for two sample scenarios, Fig. 2f highlights the strong correlation between maximum warming and cumulative emissions. The fraction of climate model runs above 2 °C (dashed line in Fig. 2f) is then our estimate for the probability of exceeding 2 °C for an individual scenario (as indicated by the dots in Fig. 3a). We focus here on 2 °C relative to pre-industrial levels, as such a warming limit has gained increasing prominence in science and policy circles as a goal to prevent dangerous climate change[25]. We recognize that 2 °C cannot be regarded as a 'safe level', and that (for example) small island states and least developed countries are calling for warming to be limited to 1.5 °C (Supplementary Information). We chose the twenty-first century as our time horizon, as this time frame is sufficiently long to determine which emission scenarios will probably lead to a global surface warming below 2 °C. Under these scenarios, temperatures have stabilized or peaked by 2100, while warming continues under higher scenarios.

For our illustrative distribution of climate system properties, we find that the probability of exceeding 2 °C can be limited to below 25% (50%) by keeping 2000–49 cumulative CO_2 emissions from fossil sources and land use change to below 1,000 (1,440) Gt CO_2 (Fig. 3a and Table 1). If we resample model parameters to reproduce 18 published climate sensitivity distributions, we find a 10–42% probability of exceeding 2 °C for such a budget of 1,000 Gt CO_2. If the acceptable exceedance probability were only 20%, this would require an emission budget of 890 Gt CO_2 or lower (illustrative default). Given that around 234 Gt CO_2 were emitted between 2000 and 2006 and assuming constant rates of 36.3 Gt CO_2 yr^{-1} (ref. 3) thereafter, we would exhaust the CO_2 emission budget by 2024, 2027 or 2039, depending on the probability accepted for exceeding 2 °C (respectively 20%, 25% or 50%).

To contrast observationally constrained probabilistic projections against current AOGCM and carbon-cycle models, we ran each emission scenario with all permutations of 19 CMIP3[26] AOGCM and 10 C4MIP carbon-cycle model emulations[16]. The allowed emissions are similar to the lower part of the range spanned by the observationally constrained distributions, suggesting that the current AOGCMs do not substantially over- or underestimate future climate change compared to the values obtained using a model constrained by observations, although no probability statement can be derived from the proportion of runs exceeding 2 °C (black dashed line in Fig. 3a). Using an independent approach focusing on CO_2 alone, Allen *et al.*[27]

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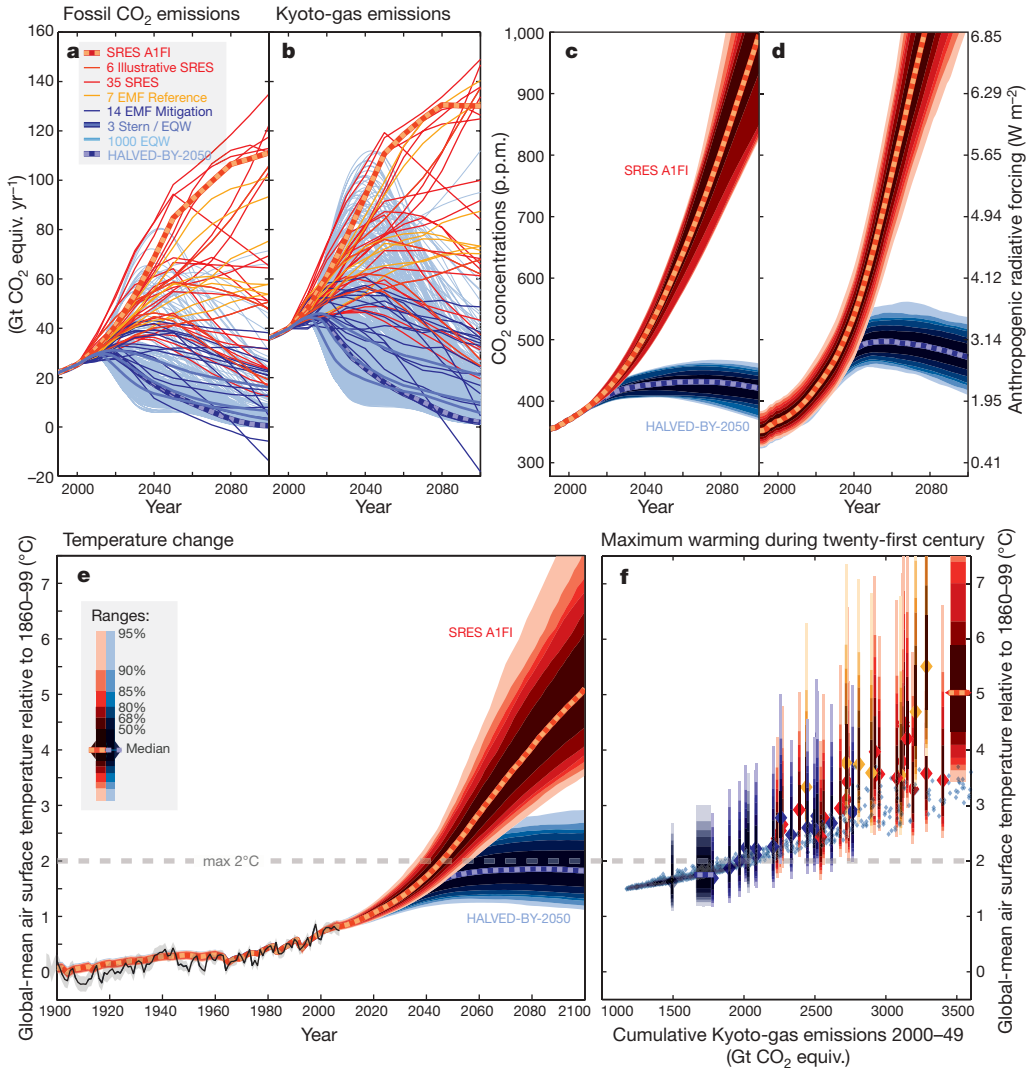


Figure 2 | Emissions, concentrations and twenty-first century global-mean temperatures. **a**, Fossil CO_2 emissions for IPCC SRES[21], EMF-21[20] scenarios and a selection of equal quantile walk[24] (EQW) pathways analysed here; **b**, GHGs, as controlled under the Kyoto Protocol; **c**, median projections and uncertainties based on our illustrative default case for atmospheric CO_2 concentrations for the high SRES A1FI[21] and the low HALVED-BY-2050[30] scenario, which halves 1990 global Kyoto-gas emissions by 2050; **d**, total anthropogenic radiative forcing; **e**, surface air global-mean temperature; **f**, maximum temperature during the twenty-first century versus cumulative Kyoto-gas emissions for 2000–49. Colour range shown in **e** also applies to **c**, **d** and **f**.

find that a range of 2,050–2,100 Gt CO_2 emissions from year 2000 onwards cause a most likely CO_2-induced warming of 2 °C: in the idealized scenarios they consider that meet this criterion, between 1,550 and 1,950 Gt CO_2 are emitted over the years 2000 to 2049.

We explored the consequences of burning all proven fossil fuel reserves (the fraction of fossil fuel resources that is economically recoverable with current technologies and prices: Fig. 3b and Methods). We derived a mid-estimate of 2,800 Gt CO_2 emissions from the literature, with an 80%-uncertainty range of 2,541 to 3,089 Gt CO_2. Emitting the carbon from all proven fossil fuel reserves would therefore vastly exceed the allowable CO_2 emission budget for staying below 2 °C.

Although the dominant anthropogenic warming contribution is from CO_2 emissions, non-CO_2 GHG emissions add to the risk of exceeding warming thresholds during the twenty-first century. We estimate that the so-called non-CO_2 'Kyoto gases' (methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and SF_6) will constitute roughly one-third of total CO_2 equivalent (CO_2 equiv.) emissions based on 100-yr global warming potentials[28] over the 2000–49 period. Under our illustrative distribution for climate system properties, and taking into account all positive and negative forcing agents as provided by Table 2.12 in AR4[17], the cumulative Kyoto-gas emission budget for 2000–50 is 1,500 (2,000) Gt CO_2 equiv., if the probability of exceeding 2 °C is to be limited to approximately 25% (50%) (Table 1).

For the lower scenarios, Kyoto-gas emissions in the year 2050 are a remarkably good indicator for probabilities of exceeding 2 °C, because for these scenarios (with emissions in 2050 below ~30 Gt CO_2 equiv.), radiative forcing peaks around 2050 and temperature soon thereafter. This is indicated by the narrow spread of individual scenarios' exceedance probabilities for similar 2050 Kyoto-gas emissions, as shown in Supplementary Fig. 1b. If emissions in 2050 are half 1990 levels, we estimate a 12–45% probability of exceeding 2 °C (Table 1) under these scenarios.

Emissions in 2020 are a less robust indicator of maximum warming (note the wide vertical spread of individual scenario dots in Supplementary Fig. 1c)—even if restricted to this class of relatively smooth emission pathways. However, the probability of exceeding 2 °C rises to 75% if 2020 emissions are not lower than 50 Gt CO_2 equiv. (25% above 2000). Given the substantial recent increase in fossil CO_2 emissions (20% between 2000 and 2006)[3], policies to reduce global emissions are needed urgently if the 'below 2 °C' target[29] is to remain achievable.

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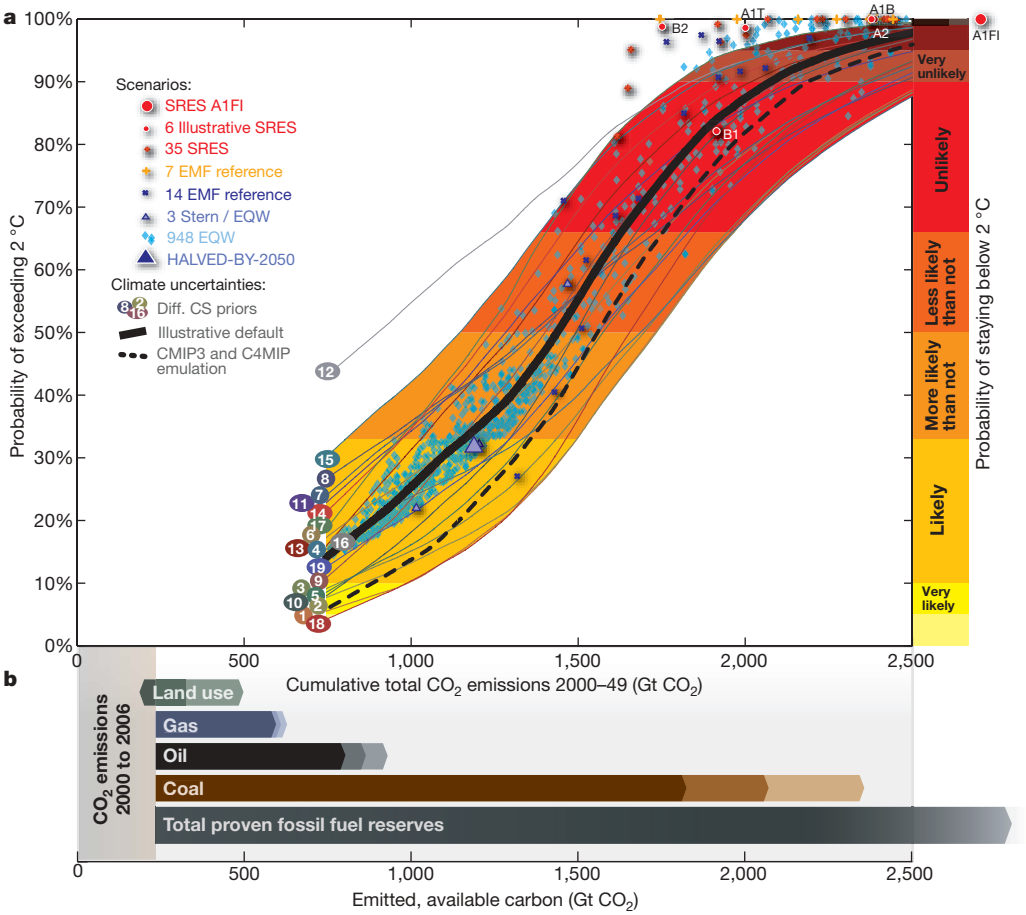


Figure 3 | The probability of exceeding 2 °C warming versus CO_2 emitted in the first half of the twenty-first century. **a**, Individual scenarios' probabilities of exceeding 2 °C for our illustrative default (dots; for example, for SRES B1, A2, Stern and other scenarios shown in Fig. 2) and smoothed (local linear regression smoother) probabilities for all climate sensitivity distributions (numbered lines, see Supplementary Information for data sources). The proportion of CMIP3 AOGCMs[26] and C4MIP carbon-cycle[8] model emulations exceeding 2 °C is shown as black dashed line. Coloured areas denote the range of probabilities (right) of staying below 2 °C in AR4 terminology, with the extreme upper distribution (12) being omitted. **b**, Total CO_2 emissions already emitted[3] between 2000 and 2006 (grey area) and those that could arise from burning available fossil fuel reserves, and from land use activities between 2006 and 2049 (median and 80% ranges, Methods).

Table 1 | Probabilities of exceeding 2 °C

Indicator	Emissions	Probability of exceeding 2 °C*	
		Range	Illustrative default case‡
Cumulative total CO_2 emission 2000–49	886 Gt CO_2	8–37%	20%
	1,000 Gt CO_2	10–42%	25%
	1,158 Gt CO_2	16–51%	33%
	1,437 Gt CO_2	29–70%	50%
Cumulative Kyoto-gas emissions 2000–49	1,356 Gt CO_2 equiv.	8–37%	20%
	1,500 Gt CO_2 equiv.	10–43%	26%
	1,678 Gt CO_2 equiv.	15–51%	33%
	2,000 Gt CO_2 equiv.	29–70%	50%
2050 Kyoto-gas emissions	10 Gt CO_2 equiv. yr^{-1}	6–32%	16%
	(Halved 1990) 18 Gt CO_2 equiv. yr^{-1}	12–45%	29%
	(Halved 2000) 20 Gt CO_2 equiv. yr^{-1}	15–49%	32%
	36 Gt CO_2 equiv. yr^{-1}	39–82%	64%
2020 Kyoto-gas emissions	30 Gt CO_2 equiv. yr^{-1}	(8–38%)†	(21%)†
	35 Gt CO_2 equiv. yr^{-1}	(13–46%)†	(29%)†
	40 Gt CO_2 equiv. yr^{-1}	(19–56%)†	(37%)†
	50 Gt CO_2 equiv. yr^{-1}	(53–87%)†	(74%)†

* Range across all priors reflecting the various climate sensitivity distributions with the exception of line 12 in Fig. 3a.
† Note that 2020 Kyoto-gas emissions are, from a physical perspective, a less robust indicator for maximal twenty-first century warming with a wide scenario-to-scenario spread (Supplementary Fig. 1c).
‡ Prior chosen to match posterior of ref. 19 with uniform priors on the TCR.

METHODS SUMMARY

To relate emissions of GHGs, tropospheric ozone precursors and aerosols to gas-cycle and climate system responses, we employ MAGICC 6.0[16], a reduced complexity coupled climate–carbon cycle model used in past IPCC assessment reports for emulating AOGCMs. Out of more than 400 parameters, we vary 9 climate response parameters (one of which is climate sensitivity), 33 gas-cycle and global radiative forcing parameters (not including 18 carbon-cycle parameters, which are calibrated separately[16] to C4MIP carbon-cycle models[8]), and 40 scaling factors determining the regional 4 box pattern of key forcings (Supplementary Table 1). Other parameters are set to default values[16].

To constrain the parameters, we use observational data of surface air temperature[9] in 4 spatial grid boxes from 1850 to 2006, the linear trend in ocean heat content changes[10] from 1961 to 2003 and year 2005 radiative forcing estimates

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for 18 forcing agents[17], in addition to a constraint on the twenty-first century change of effective climate sensitivity derived from AOGCM CMIP3 emulations[16]. With a Metropolis-Hastings Markov chain Monte Carlo approach, based on a large ensemble ($>3 \times 10^6$) of parameter sets using 45 parallel Markov chains with 75,000 runs each, we estimate the posterior distribution of different MAGICC parameters. Estimated likelihoods take into account observational uncertainty and climate variability from various AOGCM control runs, HadCM3 being the default.

For forward projections with the model, we combine, at random, 600 sets of the 82 historically constrained parameters with one of 10 carbon-cycle calibrations. We supplemented 26 multi-gas IPCC SRES[21] and 20 EMF-21 reference and mitigation scenarios[20] by 948 equal quantile walk multi-gas pathways[24]. The proven fossil fuel reserve estimates for natural gas, oil and coal were compiled from various sources[4,5] by combining the reserve estimates with net calorific values and emission factors (and their 95% uncertainty ranges) according to IPCC 2006 guidelines[6] (Supplementary Information).

Full Methods and any associated references are available in the online version of the paper at www.nature.com/nature.

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METHODS

Coupled carbon cycle–climate model. We use a reduced complexity coupled carbon cycle climate model (MAGICC 6.0), requiring (hemispheric) emissions of GHGs, aerosols, and tropospheric ozone precursors as inputs for calculating atmospheric concentrations, radiative forcings, surface air temperatures, and ocean heat uptake. MAGICC is able to closely emulate both CMIP3[26] AOGCMs and C4MIP[8] carbon-cycle models, and has been used extensively in past IPCC assessment reports[16]. We use MAGICC 6.0 here both for future climate projections based on historical constraints and for emulating more complex AOGCMs or carbon-cycle models. The model contains many parameters whose values are uncertain. We looked at the impact of 82 parameters on model behaviour, which are summarized in the vector $\mathbf{\Theta}$.

Observational constraints. As one set of observational constraints, we use yearly averaged temperatures in our four grid boxes (Northern and Southern Hemisphere Land and Ocean) as provided in ref. 9 for the years 1850–2006. We arrange those measurements in a 628-dimensional vector $\mathbf{T}$. The respective space-time dependency of the errors is obtained from ref. 9. We use the full-length control runs of all AOGCMs runs available at PCMDI (http://www-pcmdi.llnl.gov/, as of mid-2007) to assess internal variability. We project the 628-dimensional vector of temperature observations into a low-dimensional subspace. We choose m so that 99.95% of the MAGICC variance is preserved and find that an eight-dimensional subspace is sufficient but findings are insensitive to this choice. We then find the $m \times 628$-dimensional matrix P_m, which corresponds to the projection of $\mathbf{T}$ into the space spanned by the first m PCA components. The likelihood is finally based on the m-dimensional vector $\mathbf{T}_m = P_m\mathbf{T}$ instead of the 628-dimensional vector $\mathbf{T}$. We now assume that the internal variability of $\mathbf{T}_m$ has a Gaussian distribution and estimate the $m \times m$-dimensional covariance matrix Σ_m from the data set as $P_m \Sigma {P_m}^T$, where Σ is the previously derived covariance matrix of the observations (including internal variability and measurement errors).

Ocean heat uptake is only considered via its linear trend Z_1 of $+0.3721$ (1σ: ± 0.0698) 10^{22} J yr^{-1} for the heat content trend over 1961 to 2003 up to 700 m depth[10]. See Supplementary Fig. 2 for the match between the constrained model results and the observational data[31] as well as more recent results[10].

Radiative forcing estimates as listed in ref. 17 (Table 2.12 therein) provide an additional set of 17 constraints $Z_2,\ldots,Z_{18}$ (Supplementary Table 2). The error of 14 of these radiative forcing estimates is assumed to have a Gaussian distribution. The remaining 3 observational constraints, however, exhibit skewness, which we model by a distribution we call here 'skewed normal' (Supplementary Information). All radiative forcing uncertainties are assumed to be independent.

Given that MAGICC 6.0 has substantially more freedom to change the effective climate sensitivity over time[16] than what is observed from AOGCM diagnostics, we introduce another constraint Z_{19}. This constraint limits the ratio of the twenty-first century change in effective climate sensitivity, expressed by the ratio of average effective climate sensitivities in the periods 2050–2100 and 1950–2000. Based on AOGCM CMIP3 model emulations[16], we derive a distribution with a median at 1.23 (with a 90% range between 1.06 to 1.51) under the SRES A1B scenario.

Likelihood estimation. To calculate the likelihood, the observations are split into the projected temperature observations $\mathbf{T}_m$ and the remaining observational constraints $Z_1,\ldots,Z_{19}$. Let f be the density of temperature observations under a given parameter setting $\mathbf{\Theta}$, taking into account both the measurement errors and internal climate variability. Let h_k, $k = 1,\ldots,19$, be the density functions of the remaining observational constraints. Under independence of $Z_1,\ldots,Z_{19}$ and $\mathbf{T}$, the likelihood $L(\mathbf{\Theta})$ of model parameters $\mathbf{\Theta}$ is given by:

$$L(\mathbf{\Theta}) = f(T_m|\mathbf{\Theta}) \prod_{k=1}^{19} h_k(Z_k|\mathbf{\Theta})$$

We follow mostly a Bayesian approach. A prior distribution π over the parameter vector $\mathbf{\Theta}$ is specified in various ways as discussed further below, see Supplementary Table 1 for prior assumption on key parameters. Given the a priori assumption, we are able to specify the posterior distribution $g(\mathbf{\Theta})$ of the parameters as proportional to the product of the likelihood $L(\mathbf{\Theta})$ and the prior $\pi(\mathbf{\Theta})$.

Sensitivity to the chosen prior and a comparison with frequentist inference are discussed further below. For frequentist inference, we work directly with the likelihood.

Model sampling. To draw models from the posterior distribution $g(\mathbf{\Theta})$, we use a Markov chain Monte Carlo approach and a standard Metropolis-Hastings algorithm with adaptive step sizes to attain an average acceptance rate of 60%. 45 Markov chains are run in parallel for 75,000 iterations each. Adjusting for a burn-in time of 20,000 iterations, and retaining only every 30th model, to decrease dependence between successive models, a total of 82,500 models are drawn from the posterior distribution. For probabilistic forecasts, 600 models with maximal spacing in this set of 82,500 models are retained and combined randomly with one of the 10 parameter sets used for emulating individual C4MIP carbon-cycle models[16].

Representation of climate sensitivity distributions. Apart from the frequentist likelihood confidence intervals, we represent the wide range of literature studies on Bayesian climate sensitivity distributions[19,32–41]. Specifically, we change the prior for climate sensitivity such that a match between our posterior PDF of climate sensitivity and the posterior distribution in the considered studies is achieved.

Fossil fuel reserves. Our median estimates of proven recoverable fossil fuel reserves are based on ref. 42, with the exception of the non-conventional oil reserves which are taken as the median between ref. 43 and ref. 44. Potential emissions are estimated using IPCC 2006 default net calorific values and carbon content emission factors[6] (Table 1.2 and Table 1.3 therein).

We estimate the 80% uncertainty range in these reserve estimates as being $\pm 10\%$ of the WEC[42] estimates or the range of estimates in the literature[4,43–46], whichever is greater, for individual classes of reserves. We combine these reserve uncertainties with the provided 95% ranges of calorific values and emission factors for each class of energy reserves[6] (Supplementary Table 3). See Supplementary Information for an expanded description of the methods.

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A globally coherent fingerprint of climate change impacts across natural systems

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Causal attribution of recent biological trends to climate change is complicated because non-climatic influences dominate local, short-term biological changes. Any underlying signal from climate change is likely to be revealed by analyses that seek systematic trends across diverse species and geographic regions; however, debates within the Intergovernmental Panel on Climate Change (IPCC) reveal several definitions of a 'systematic trend'. Here, we explore these differences, apply diverse analyses to more than 1,700 species, and show that recent biological trends match climate change predictions. Global meta-analyses documented significant range shifts averaging 6.1 km per decade towards the poles (or metres per decade upward), and significant mean advancement of spring events by 2.3 days per decade. We define a diagnostic fingerprint of temporal and spatial 'sign-switching' responses uniquely predicted by twentieth century climate trends. Among appropriate long-term/large-scale/multi-species data sets, this diagnostic fingerprint was found for 279 species. This suite of analyses generates 'very high confidence' (as laid down by the IPCC) that climate change is already affecting living systems.

The Intergovernmental Panel on Climate Change[1] (IPCC) assessed the extent to which recent observed changes in natural biological systems have been caused by climate change. This was a difficult task despite documented statistical correlations between changes in climate and biological changes[2–5]. With hindsight, the difficulties encountered by the IPCC can be attributed to the differences in approach between biologists and other disciplines, particularly economists. Studies in this area are, of necessity, correlational rather than experimental, and as a result, assignment of causation is inferential. This inference often comes from experimental studies of the effects of temperature and precipitation on the target species or on a related species with similar habitats. Confidence in this inferential process is subjective, and differs among disciplines, thus resulting in the first divergence of opinion within the IPCC.

The second impasse came from differences in perspective on what constitutes an 'important' factor. Anyone would consider a currently strong driver to be important, but biologists also attach importance to forces that are currently weak but are likely to persist. In contrast, economic approaches tend to discount events that will occur in the future, assigning little weight to weak but persistent forces. Differences of opinion among disciplines can therefore stem naturally from whether the principal motivation is to assess the magnitude of immediate impacts or of long-term trajectories. Most field biologists are convinced that they are already seeing important biological impacts of climate change[1–4,6–9]; however, they have encountered difficulty in convincing other academic disciplines, policy-makers and the general public. Here, we seek to improve communication, provide common ground for discussion, and give a comprehensive summary of the evidence.

How should a 'climate fingerprint' be defined? A straightforward view typical of an economist would be to conclude that climate change was important if it were principally responsible for a high proportion of current biotic changes. By this criterion a climate fingerprint appears weak. Most short-term local changes are not caused by climate change but by land-use change and by natural fluctuations in the abundance and distribution of species. This fact has been used by non-biologists to argue that climate change is of little importance to wild systems[10]. This approach, however, effectively ignores small, systematic trends that may become important in the longer term. Such underlying trends would be confounded (and often swamped) by strong forces such as habitat loss. Biologists have tended to concentrate on studies that minimize confounding factors, searching for trends in relatively undisturbed systems and then testing for significant associations with climate change. Economists have viewed this as biased (nonrandom exclusion of data) whereas biologists view this as reducing non-climatic noise. Thus, economists focus on total direct evidence and apply heavy time discounting; biologists apply a 'quality control' filter to available data, accept indirect (inferential) evidence and don't apply time discounting.

The test for a globally coherent climate fingerprint does not require that any single species show a climate change impact with 100% certitude. Rather, it seeks some defined level of confidence in a climate change signal on a global scale. Adopting the IPCC 'levels of confidence'[11] and applying the economists' view of a fingerprint, we would have "very high confidence" in a fingerprint if we estimated that more than 95% of observed changes were principally caused by climate change, "high confidence" between 95% and 67%, "medium confidence" between 33% and 67%, and "low confidence" below 33%. In contrast, the biologists' confidence level comes from the statistical probability that global biotic trends would match climate change predictions purely by chance, coupled with supporting experimental results showing causal relationships between climate and particular biological traits.

Here, we present quantitative estimates of the global biological impacts of climate change. We search for a climate fingerprint in the overall patterns, rather than critiquing each study individually. Using the biologists' approach, we synthesize a suite of correlational studies on diverse taxa over many regions to ask whether natural systems, in general, have responded to recent climate change. Furthermore, we attempt a cross-fertilization by applying an economists' measure—the estimated proportion of observed changes for which climate trends are the principal drivers—to data sets chosen using biologists' criteria. We call this a 'global coherence' approach to the detection of climate change impacts.

First, we explore a biologists' confidence assessment with two types of analyses of observed change: statistical meta-analyses of effect size in restricted data sets and more comprehensive categorical analyses of the full literature. Second, we present a probabilistic model that considers three variables: proportion of observations matching climate change predictions, numbers of competing explanations for each of those observations, and confidence in causal

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attribution of each observation to climate change. These three variables feature equally in a model that explores an economists' 'confidence' assessment. Finally, we explore diagnostic 'sign-switching' patterns that are predicted uniquely by climate change.

The evidence

A few studies indicate evolutionary responses of particular species to climate change[12–14], but the generality of evolutionary response remains unknown. Here, we focus on phenological (timing) shifts, range boundary shifts, and community studies on species abundances (Table 1).

Meta-analyses

We developed databases suitable for meta-analysis[15] on two phenomena: range-boundary changes and phenological shifts. To control for positive publishing bias, we used only multi-species studies that reported neutral and negative results as well as positive (see Methods).

For range boundaries, suitable data spanned 99 species of birds[16], butterflies[17] and alpine herbs[18,19] (see Methods). The meta-analysis showed that the range limits of species have moved on average 6.1 ($\pm$2.4) km per decade northward or m per decade upward, significantly in the direction predicted by climate change (bootstrapped 95% confidence interval of the mean (CI_{mean}) = 1.3–10.9 km m^{-1} per decade; one-sample *t*-test, degrees of freedom (d.f.) = 98, $t = 2.52$, $P = 0.013$; Table 2).

For phenologies, suitable data were reported for herbs[20–23], shrubs[20–25], trees[20,23–25], birds[20,21], butterflies[26] and amphibians[27,28], a total of 172 species (see Methods). There was a mean shift towards earlier spring timing of 2.3 days per decade, with a bootstrapped 95% CI of 1.7–3.2 days advancement per decade (significant at $P < 0.05$).

Categorical analyses

The remaining studies were not included in the meta-analyses, either because they were on single species or because they did not present data in the raw form of *x* unit change per *y* time units per species. These less-detailed data were simplified into four categories: changed in accord with or opposite to climate change predictions, changed in some other fashion or stable (see Methods).

As with previous studies[17], analyses ignore species classified as 'stable'. This category does not represent a single result, as apparent stability could arise from a diversity of situations[17] such as: 1) the phenology, abundance or distribution of the species is not driven by climatic factors; 2) the species is actually changing, but poor data resolution could not detect small changes; and 3) the phenology, abundance or distribution of the species is driven by climatic factors, but fails to respond to current climate change. Such failure could stem from anthropogenic barriers to dispersal (habitat fragmentation) or from a lag in response time. Lags are expected when limited dispersal capabilities retard poleward/upward colonization[29], or when a necessary resource has slower response time than the focal species[17].

Phenological shifts. We quantitatively assessed 677 species reported in the literature (Table 1). Over a time period range of 16–132 years (median 45 yrs), 27% showed no trends in phenologies, 9% showed trends towards delayed spring events, whereas the remaining 62% showed trends towards spring advancement. Observed trends include earlier frog breeding[27,28], bird nesting[30–32], first flowering[20–25], tree budburst[23–25], and arrival of migrant birds and butterflies[20,21,26,33] (Table 1). Shifts in phenologies that have occurred are overwhelmingly (87%) in the direction expected from climate change ($P < 0.1 \times 10^{-12}$; Table 2).

Distribution/abundance shifts. In a quantitative assessment covering >1,046 species, we were able to categorize 893 species, functional

Table 1 **Summary of data studying phenological and distributional changes of wild species**

Taxon	Ref. number	Total no. of species (or species groups)	Spatial scale			Time scale (range years)	Change in direction predicted (*n*)	Change opposite to prediction (*n*)	Stable (*n*)	No prediction (*n*)
			L	R	C					
Phenological changes										
Woody plants	20,23,24*,25*	*n* = 38 sp		2	1	35–132	30	1	7	–
Herbaceous plants	20,21*	*n* = 38 sp	1	1		63–132	12	–	26	–
Mixed plants	22*	*n* = 385 sp	1			46	279	46	60	–
Birds	20,21*,30,31,32,33	*n* = 168 sp	2	3	1	21–132	78	14	76	–
Insects	26	*n* = 35 sp		1		23	13	–	22	–
Amphibians	27,28	*n* = 12 sp	2			16–99	9	–	3	–
Fish	20	*n* = 2 sp		1		132	2	–	–	–
Distribution/abundance changes										
Tree lines	54,55,56*	*n* = 4 sp + 5 grps	2	1		70–1,000	3 sp + 5 grps	–	1	–
Herbs and shrubs	18,19,41*,42*	*n* > 66 sp, 15 detailed		3		28–80	13	2	–	–
Lichens	36	4 biogeographic grps (*n* = 329 sp)	1			22	43	9	113	164
Birds	8*	*n* = 3 sp		1		50	3	–	–	–
	16,57*	N sp (*n* = 46 sp)		2		20–36	13	15	18	
		S sp (*n* = 73 sp)		2		20–36	36	16	21	6
	43*	Low elevation (>91 sp)	1			20	71	11	9	–
		High elevation (>96 sp)	1			20	37	27	32	–
Mammals	37	*n* = 2 sp		1		52	2	–	–	–
Insects	17,49*	*n* = 36 sp		1	1	98–137	23	2	10	1
	17	N boundaries (*n* = 52 sp)		1		98	34	1	17	–
		S boundaries (*n* = 40 sp)		1		98	10	2	28	–
Reptiles and amphibians	43*	*n* = 7 sp	1			17	6	–	1	–
Fish	39	*4* biogeographic grps (*n* = 83 sp)	1			–	2 grps	–	1 grp	1 grp
	40*	N sp (*n* > 1 sp)		1		70	>1	–	–	–
		S sp (*n* > 1 sp)		1		70	>1	–	–	–
Marine invertebrates	34*,40*	N sp (*n* > 21)	1	1		66–70	>19	2	–	>1 sp not classified
		S sp (*n* > 21)	1	1		66–70	>20	1	–	
		Cosmopolitan sp (*n* = 28 sp)	1			66	–	–	–	28
Marine zooplankton	40*	Cold water (*n* > 10 sp)		1		70	>10	–	–	>8 sp not classified
		Warm water (*n* > 14 sp)		1		70	>14	–	–	
	35	6 biogeographic grps (*n* ≥ 36 sp)			1	39	6 grps	–	–	–

N, species with generally northerly distributions (boreal/arctic); S, species with generally southerly distributions (temperate); L, local; R, regional (a substantial part of a species distribution; usually along a single range edge); C, continental (most or the whole of a species distribution). No prediction indicates that a change may have been detected, but the change was orthogonal to global warming predictions, was confounded by non-climatic factors, or there is insufficient theoretical basis for predicting how species or system would change with climate change.

*Study partially controlled for non-climatic human influences (for example, land-use change). Studies that were highly confounded with non-climatic factors were excluded. (See Supplementary Information for details of species classification.)

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groups or biogeographic groups (Table 1). Less than one-third (27%) of these have exhibited stable distributions during the twentieth century. Others (24%) show changes that are impossible to relate to climate change predictions. These two types of result neither support nor refute a climate change signal, although it will be important for predictive biological models to eventually determine what proportion of these are truly stable systems.

Some range shifts have been measured directly at range boundaries, whereas others have been inferred from abundance changes within local communities. Over all of the range and abundance shift data, 434 species were categorized as changing over time periods of 17–1,000 years (median 66 years) (Table 1). Of these, 80% have shifted in accord with climate change predictions (see Methods) ($P < 0.1 \times 10^{-12}$; Table 2). New species have colonized previously 'cool' regions, including sea anemones in Monterey Bay[34] and lichens and butterflies in Europe[17,36], whereas some Arctic species have contracted in range size[35,37]. Over the past 40 years, maximum range shifts vary from 200 km (butterflies[17]) to 1,000 km (marine copepods[34]).

Probabilistic coherence

How strong is the climate change signal in the light of confounding factors and lack of experimentation? We investigate this argument in a probabilistic context. We formulated a probabilistic model to ask whether a climate change fingerprint exists in a disparate set of n observed biological changes. Let n'/n indicate the proportion of observations counter to climate change predictions and p indicate the probability that climate change is the only possible causal agent of the observed biological change in any of the $n - n'$ species that do conform to climate change predictions. In practice, this can be estimated across a set of species by assigning each species a 0 or a 1, depending on whether or not competing explanations exist; p then is the proportion of species that have no competing explanations.

Competing (non-climatic) explanations can, therefore, be expected in $\{(1 - p)(n - n')\}$ of the reported analyses. Finally, for any of the $n - n'$ climate-conforming species, let π indicate the probability, determined from previous empirical study, that climate change is the principal causal agent of a particular biological change (independent of p).

These three variables, each varying from 0 to 1, are inputs to a binomial probability model whose output estimates the proportion of all species that are, in truth, being impacted by climate change. In practice, confounding factors can never be eliminated completely from observational studies; therefore, p would normally have a low value. Here, we consider only the conservative case where $p = 0$; that is, we assume that non-climatic alternative explanations exist for every species. In the Supplementary Information, we present modelling schemes where p varies from 0 to 1.0.

The importance of non-climatic explanations should decrease with increasing scale. Most local changes are idiosyncratic and consist of noise when scaled up; however, atmospheric carbon dioxide levels have risen nearly uniformly across the globe. Increased CO_2 can directly cause earlier flowering[38], as does increased temperature, making these effects difficult to separate. However, these two effects can be viewed as different aspects of global warming, legitimizing discussion of their joint impacts.

The variable π reflects the extent to which previous study and experimentation provides clear mechanistic understanding of the links between climate variables and a species' behaviour and ecology. To understand the importance of π, consider the case of the silver-spotted skipper butterfly (*Hesperia comma*) that has expanded its distribution close to its northern boundary in England over the past 20 years. Possible ecological explanations for this expansion are regional warming and changes in land use. Comparing the magnitudes and directions of these two factors suggests that climate change is more likely than land-use change to be the cause of expansion[29]. Deeper support was provided by previous empirical studies documenting strong thermal limitation. At the northern boundary, development of offspring was restricted to the hottest microclimates (south-facing chalk slopes). Range expansion coincided with colonization of non-southern slopes. Simulation models based solely on previously measured thermal tolerances (that is, without land-use change) closely matched the observed expansion of 16.4 km (model prediction 14.4 km)[12]. Thus, mechanistic understanding of the system generates a high estimate for π.

Figure 1 shows relationships between the n'/n proportions and the minimum value of π that would be required to sustain different degrees of confidence for $p = 0$. For example, the medium confidence region shows minimum values of π that would be required across the displayed range of n'/n proportions to guarantee that about half of the observed species impacts were in truth being driven principally by climate change. Claiming a climate fingerprint with high confidence would require high minimum values for π (>0.67) regardless of n'/n.

Applying the probabilistic model

Using all of the data from Table 2 to parameterize the model, $n' = 147$ and $n = 770$, making $n'/n = 0.16$ (16% of species changing opposite to climate change predictions). We now consider π. The extent to which climate change can be isolated as the predominant driving force is extremely variable among species and systems. Such attribution results from a subjective synthesis of experimental and observational research, often conducted well before and independently of any study of long-term trends. The species for which π is high are those with a history of basic biological research, especially where research has been conducted along several axes (controlled laboratory/greenhouse experiments, field manipulations and observations).

Table 2 **Summary statistics and synthetic analyses derived from Table 1**

Type of change	Changed as predicted	Changed opposite to prediction	*P*-value
Phenological ($N = 484/(678)$)	87% ($n = 423$)	13% ($n = 61$)	$<0.1 \times 10^{-12}$
Distributional changes			
At poleward/upper range boundaries	81%	19%	–
At equatorial/lower range boundaries	75%	25%	–
Community (abundance) changes			
Cold-adapted species	74%	26%	–
Warm-adapted species	91%	9%	–
$N = 460/(920)$	81% ($n = 372$)	19% ($n = 88$)	$<0.1 \times 10^{-12}$
Meta-analyses			
Range-boundaries ($N = 99$)	6.1 km m^{-1} per decade northward/upward shift*		0.013
Phenologies ($N = 172$)	2.3 days per decade advancement*		<0.05

Data points represent species, functional groups or biogeographic groups. *N*, number of statistically or biologically significant changes/(total number species with data reported for boundary, timing, or abundance processes). The no prediction category is not included here.
*Bootstrap 95% confidence limits for mean range boundary change are 1.26, 10.87; for mean phenological shift the limits are −1.74, −3.23.

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This sort of biological detail reveals that climate and extreme weather events are mechanistically linked to body size, individual fitness and population dynamics for diverse species[3–9] (but not for all). Species for which confidence in climate as the primary driving mechanism is low are those for which long-term observational records exist, but not detailed empirical research on target species or on ecologically similar species. The black line in Fig. 1 suggests that medium confidence can be claimed for $n'/n = 0.16$ if $0.35 < \pi < 0.7$. Other contingencies, such as complications from a positive publishing bias or non-independence among confounding factors, can be considered through variations of the model (see Supplementary Information).

Differentiating diagnostic patterns

Predictions of the impacts of climate change are not unidirectional, but may show opposite trends within communities and across long time spans or large spatial scales. Alternative causal agents would therefore have to be able to switch the sign of their impacts within a study if they were to form credible competing explanations. Such differentiating patterns greatly reduce the likelihood of hidden, non-climate competing explanations, thereby increasing P and decreasing the value of π necessary to achieve a given confidence level (see Supplementary Information). High confidence could be obtained under this scheme with existing patterns ($n'/n \leq 0.33$) and poor mechanistic understanding (low π). Sufficient data to quantify the differential impacts on species' distributions or phenologies across time periods or geographic regions were available for 334 species, among which 84% showed a sign-switching diagnostic of climate change response ($P < 0.1 \times 10^{-12}$; Table 3).

Community representation sign switching

Community studies in regions of overlapping 'polar' and 'temperate' species base their climate change attribution on differential responses of these two categories. Among marine fish and intertidal invertebrates (for example, snails, barnacles, anemones, copepods and limpets) off the Californian coast[34,39] and in the North Atlantic[35,40], lichens in the Netherlands[36], foxes in Canada[37] and birds in Great Britain[16], polar species have tended to be stable or decline in abundance, whereas temperate species at the same site have increased in abundance and/or expanded their distributions. Analogous shifts are occurring even within the Arctic and Antarctic among penguins[8], woody plants[41] and vascular plants[42]. Similar patterns exist for lowland compared with highland birds in the tropics[43]. Most of these studies are local, with high variability of individual species' population dynamics. Even so, 80% of changes in community representation are in accord with climate change predictions (Tables 2 and 3).

Temporal sign switching

Long-term studies encompass periods of climate cooling as well as warming. If the distributions of species are truly driven by climate trends, these species should show opposite responses to cooling and warming periods. Such sign switching has been documented in the United Kingdom for marine fish, limpets, barnacles and zooplankton[40], in the United Kingdom and Estonia for birds[20,31,44,45], and in the United Kingdom, Finland and Sweden for butterflies[17,46–48] (see also Table 3 legend). A typical pattern includes northward range shifts during the two twentieth-century warming periods (1930–45 and 1975–99), and southward shifts during the intervening cooling period (1950–70). No species showed opposing temporal trends (Table 3).

Spatial sign switching

Whole-range, continental-scale studies, by encompassing the extremes of a species' distribution, allow testing for differential spatial impacts. In North America and Europe, detailed temporal data spanning the twentieth century were compiled for 36 butterfly species at both northern and southern range extremes[17,49]. Eight species (22%) exhibited a diagnostic pattern of northward expansion (new colonizations) and southern contraction (population extinctions). No species showed opposing range shift trends (northward contraction and southward expansion) (Table 3).

Discussion

The logic of a global focus on biological change is analogous to that for climate change itself. With climate change, attribution of recent warming trends to changes in atmospheric gases comes from analysis of global patterns, not from detailed data from individual meteorological stations. Similarly, when assessing biological

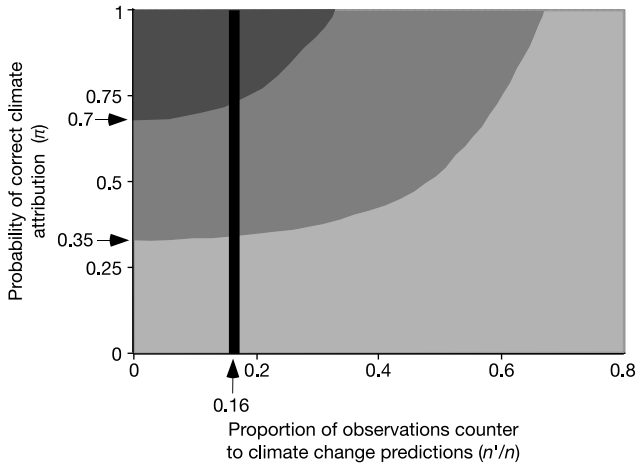


Figure 1 Probabilistic model based on parameter estimates from a review of the literature. Levels of confidence in the linkage of biological changes to global climate change are: high (dark grey), medium (mid-grey) and low (light grey). Confidence regions assume $p = 0$ (competing explanations exist for all studies). The black line indicates the region of confidence possible using the probabilistic model on the basis of the parameter estimate of n'/n from the literature review, and allowing π to vary freely.

Table 3 **Biological fingerprint of climate change impacts**

Sign-switching pattern	Percentage of species showing diagnostic pattern
Community	
Abundance changes have gone in opposite directions for cold-adapted compared with warm-adapted species. Usually local, but many species in each category. Diverse taxa, $n = 282$*.	80%
Temporal	
Advancement of timing of northward expansion in warm decades (1930s/40s and 1980s/90s); delay of timing or southward contraction in cool decades (1950s/60s), 30–132 years per species. Diverse taxa, $n = 44$*.	100%
Spatial	
Species exhibit different responses at extremes of range boundary during a particular climate phase. Data are from substantial parts of both northern and southern range boundaries for each species. All species are northern hemisphere butterflies, $n = 8$*.	100%

Differential sign-switching patterns diagnostic of climate change as the underlying driver.
*Numbers of species represent minimum estimates, as not all species were described in sufficient detail in each study to classify. A few species showed two types of sign switching, and so are included in more than one cell. Data are from references in text and from raw data provided by L. Kaila, J. Kullberg, J. J. Lennon, N. Ryrholm, C. D. Thomas, J. A. Thomas and M. Warren.

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impacts, the global pattern of change is far more important than any individual study.

The approach of biologists selects study systems to minimize confounding factors and deduces a strong climate signal both from systematic trends across studies and from empirically derived links between climate and biological systems. This deduction is made even if climate explains only a small part of the observed biological change. The meta-analyses of 334 species and the global analyses of 1,570 species (or functional/biogeographic groups) show highly significant, nonrandom patterns of change in accord with observed climate warming in the twentieth century, indicating a very high confidence (>95%) in a global climate change fingerprint (Table 2).

The approach of economists takes a broader view. In its purest form, applied to all existing data and incorporating time discounting, this approach would conclude that climate change has little total impact on wild species. We argue that this approach misses biologically important phenomena. Here we hybridize the two approaches by applying an economists' model to data that biologists would consider reasonable, and forego time discounting. A total of 74–91% of species that have changed have done so in accord with climate change predictions (Table 2) giving an estimate of $n'/n = 0.16$ for the hybrid model. Assessment of π, the probability of correct attribution to climate, is subjective and relies on the level of confidence in inferential evidence. Such evidence comes from empirical analyses and experimental manipulations, which have documented the importance of climatic variables to the dynamics, distributions and behaviour of species[3,5,8,9]. From these studies, biologists infer that expected values of π are often high. We show that moderate values of π (0.35–0.70) are consistent with medium confidence in a global climate change fingerprint.

The different approaches raise two distinct questions of the data and result in different levels of confidence in a climate change fingerprint. The questions are: (1) whether climate change can be shown to be an over-riding factor currently driving natural systems; and (2) whether there is sufficient evidence to implicate climate change as a common force impacting natural systems on a global scale. In an absolute sense, land-use change has probably been a stronger driver of twentieth century changes in wild plants and animals than has climate change (question 1). From a biological view, however, finding any significant climate signal amidst noisy biological data is unexpected in the absence of real climate drivers (question 2). Such small, persistent forces are inherently important in that they can alter species interactions, de-stabilize communities and drive major biome shifts.

A review of the literature reveals that the patterns that are being documented in natural systems are surprisingly simple, despite the real and potential complexity of biotic change. Change in any individual species, taxon or geographic region may have a number of possible explanations, but the overall effects of most confounding factors decline with increasing numbers of species/systems studied. Similarly, uncertainty in climate attribution for any particular study does not prevent the development of a global conclusion on the basis of a cumulative synthesis. In particular, a clear pattern emerges of temporal and spatial sign switches in biotic trends uniquely predicted as responses to climate change. With 279 species (84%) showing predicted sign switches, this diagnostic indicator increases confidence in a climate change fingerprint from either viewpoint.

The published IPCC conclusion stated high confidence ($P > 0.67$) in a climate signal across observed biotic and abiotic changes. Analyses presented here support that conclusion. Furthermore, a driver of small magnitude but consistent impact is important in that it systematically affects century-scale biological trajectories and ultimately the persistence of species. The climate fingerprint found here implicates climate change as an important driving force on natural systems. □

Methods

Climate change predictions

Expected phenological shifts for regions experiencing warming trends are for earlier spring events (for example, migrant arrival times, peak flight date, budburst, nesting, egg-laying, and flowering) and for later autumn events (for example, leaf fall, migrant departure times, and hibernation)[50,51]. Response to climate warming predicts a preponderance of polward/upward shifts[50,51]. Dynamics at the range boundaries are expected to be more influenced by climate than are dynamics within the interior of a species range. Thus, community level studies of abundance changes are used best to infer range shifts when they are located at ecotones involving species having fundamentally different geographic ranges: higher compared with lower latitudes, or upper compared with lower altitudes. Response to climate warming predicts that southerly species should outperform northerly species at the same site[50,51].

Selection of studies for review

This was not an exhaustive review. The studies listed in Table 1 comprise the bulk of wild species studied with respect to climate change hypotheses. Selection of papers was aimed at those with one or more of the following attributes: long temporal span (>20 years), data covering a large geographic region, and/or data gathered in an unbiased manner for a multi-species assemblage (typically species abundance data of locally well-documented communities). We excluded several high-quality studies of single species performed at local scale or highly confounded by non-climatic global change factors. The stable category represents species for which any observed changes are indistinguishable from year to year fluctuations, either from a statistical test for trend using very long time series data or from comparing net long-term movement to expected yearly variation on the basis of basic biological knowledge of dispersal/colonization abilities.

Meta-analyses

To create databases, studies were combined that made similar types of measurements and that reported quantitative estimates of change over a specified time period. All species were used; that is, even species that are categorized as stable in Table 1 were included in the meta-analysis. We treated phenological and distributional changes separately. To minimize positive publishing bias, only multi-species studies were included.

We considered each species as an independent data point, rather than each study. Only data reported in terms of change per individual species were included. This precluded use of studies that only report mean change across a set of species.

We used only distributional studies at range boundaries. We excluded equatorial and lower elevational boundaries because of a paucity of data combined with theoretical reasons for treating these boundaries separately from poleward/upper elevational boundaries[52]. Three studies met the criteria for data detail, covering 9 alpine herbs[18,19], 59 birds[16] and 31 butterflies[17]. The geographic locations of these boundaries were non-overlapping, reducing the likelihood of correlated confounding variables. Altitude was converted to latitudinal equivalent (for temperature clines, 1 km northward = 1 m upward). The United Kingdom bird data compared mean northern boundary in 1999 to that in 1972 using the ten northernmost occupied grid cells (on 10 km^2 grids) from published atlases. The Swedish butterfly data compared mean northern boundary in the period 1971–97 to mean northern boundary in 1900–20 using the five northernmost records per year. The Swiss herb data showed changes in species assemblages over the twentieth century in fixed plots up altitudinal gradients on 26 mountains.

The effect size per species was the absolute magnitude of range boundary shift, standardized across species to be in units of km m^{-1} per decade, with northward/upslope shifts positive and southward/downslope shifts negative. Data were not skewed, and n was large. Therefore, a one-sample t-test was used to evaluate the null hypothesis of no overall trends (that is, $H_ø$: mean boundary change across all species is zero). Variances were not available for all species, so we used an unweighted analysis. We performed an additional bootstrap analysis of 95% confidence limits on the mean boundary shift (10,000 iterations)[53].

The phenological meta-analysis was on spring timing events—there were insufficient studies on autumn phenology to warrant analysis. Nine studies published magnitudes of shift over a given time period (17–61 years). They included 11 trees[20,23–25], 6 shrubs[20,21,23–25], 85 herbs[20–23], 35 butterflies[26], 21 birds[21], 12 amphibians[27,28] and 2 fish[20]. This data set was inappropriate for the t-test owing to skew, but bootstrapped confidence limits provided an estimate of the probability that the true mean shift includes zero.

For both analyses, geography and taxa are confounded. For the range boundary analysis, all bird data are from the United Kingdom, all butterfly data from Sweden, and all herb data from Switzerland. For the phenological analysis, most shrub and bird data are from the United States, butterfly data from Great Britain, and trees from Europe. Therefore, it is not meaningful to split the analyses further.

Categorical analyses

Reported data from all studies listed in Tables 1 and 3 were included in the categorical analyses. The predicted direction is a change predicted by global warming scenarios[50,51]. All studies were conducted in temperate Northern Hemisphere, except for 194 species in Costa Rica[43] and 5 species in Antarctica[8,42]. Two categories showing changes either predicted by or opposite to predictions of climate change theory were tested against the random expectation of an equal probability of observing changes in either direction. Analyses were by binomial test with $H_ø$: $P = 0.5$.

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IN THE UNITED STATES DISTRICT COURT
FOR THE WESTERN DISTRICT OF TEXAS

PERMIAN BASIN PETROLEUM ASSOCIATION; CHAVES COUNTY, NEW MEXICO; ROOSEVELT COUNTY, NEW MEXICO; EDDY COUNTY, NEW MEXICO; and LEA COUNTY, NEW MEXICO, Plaintiffs, v. DEPARTMENT OF THE INTERIOR, U.S. FISH & WILDLIFE SERVICE, S.M.R. JEWELL, in her official capacity as Secretary of the Department of the Interior, DANIEL M. ASHE, in his official capacity as Director of the United States Fish and Wildlife Service, Defendants.	)	Case No. 7:14-CV-00050-RAJ

DEFENDANTS' ADDITIONAL FILING IN SUPPORT OF THEIR OPPOSED MOTION TO AMEND THE JUDGMENT

Pursuant to the Court's January 13, 2016, order, ECF No. 112, Defendants submit the following additional filing in support of our Rule 59(e) motion to amend the Court's judgment. Although Defendants make this filing consistent with the Court's order, Defendants repeat and preserve our previously-stated objections to Plaintiffs' two untimely notices of supplemental information (ECF Nos. 102 and 110[1]) and the provision of a third opportunity for Plaintiffs to submit information and argument related to Defendants' Rule 59(e) motion long after the court-ordered due date for Plaintiffs' opposition brief. *See* ECF No. 98 (setting briefing schedule). Defendants maintain that Plaintiffs' untimely submissions should not be considered when deciding Defendants' Rule 59(e) motion. However, because the Court has indicated it will

[1] Plaintiffs' latest notice of supplemental information (ECF No. 110) is particularly egregious, as its sole purpose was submission of an unsworn statement from a non-party that included not just factual information but also legal argument. Moreover, Plaintiffs filed this notice after they represented to the Court (and Defendants) that Defendants' Rule 59(e) motion was ripe for decision. See ECF No. 109.

consider Plaintiffs' notices of supplemental information, Defendants provide the following additional information in response.

I. There Is At Least a Serious Possibility That on Remand the Service Will Be Able to Substantiate a New Listing Decision for the Lesser Prairie-Chicken

In Defendants' Rule 59(e) motion, we ask the Court to remand the U.S. Fish & Wildlife Service's ("Service") listing of the lesser prairie-chicken as a threatened species under the Endangered Species Act ("ESA") without vacatur, or at a minimum, to geographically limit vacatur to the Permian Basin and Plaintiff counties. ECF No. 95. Remand without vacatur is appropriate where there is a "serious possibility" that the Service will be able to substantiate its listing decision on remand. See Cent. & S. W. Servs., Inc. v. EPA, 220 F.3d 683, 692 (5th Cir. 2000). In a declaration filed with this Court, the Service explained that "based on the information currently available regarding the threats to the species and the progress of the conservation efforts, the Service believes that there is more than a serious possibility that it would return the lesser prairie-chicken to the List of Endangered and Threatened Wildlife on remand." ECF No. 95-1 ("First Shaughnessy Declaration") ¶ 35. The Service explained in that declaration, among other things, that:

> (1) after a long decline in the species' range and population and increasing threats, the Service assigned the lesser prairie-chicken the highest possible ESA listing priority for the species (a "listing priority number," or LPN, of 2) (id. ¶ 2);
>
> (2) the main threat to the species is habitat fragmentation, and the lesser prairie-chicken's habitat is highly fragmented, with a Service analysis finding only 20 habitat patches remaining range-wide of the size necessary to support the species over the long-term (greater than 21,000 acres) (id. ¶ 4);
>
> (3) even with a recent uptick in the bird's population (likely due to the lessening of drought conditions across much of its range), its population is still small, below even 2012 levels, and less than half of the 67,000 birds sought by the Western Association of Fish & Wildlife Agencies' ("WAFWA") Range-Wide Conservation Plan ("Range-Wide Plan" or "Plan") for the species (id. ¶ 6); and
>
> (4) given the species' continued low population numbers and still highly fragmented habitat, restoration of previously suitable habitat is urgently required, but relatively little such restoration has occurred to date (id. ¶ 15-16, 26, 32).

In short, even with the conservation efforts now underway, the species' status appears to remain

poor, the habitat remains highly fragmented, and the threats to the species remain extant. In these circumstances, re-listing is a very strong possibility and remand without vacatur is appropriate.

To be clear, the Service's assessment of the likelihood of re-listing does not mean that it believes that the Range-Wide Plan and other conservation efforts have had no conservation benefit for the species, or will not have any conservation benefit in the future. In their second supplemental filing, Plaintiffs submitted a recent statement by WAFWA expressing concern that the Service's December 15, 2015, filing (ECF No. 107) "suggests that the agency believes the [Range-Wide Plan] has been unsuccessful in conserving the species." ECF No. 110-1 at 1. Defendants made or implied no such suggestion.[2] The Service recognizes that the Range-Wide Plan has conservation benefits for the species. However, participation in the Range-Wide Plan is voluntary, and its ultimate effectiveness in restoring the lesser prairie-chicken and its habitat to a healthy and secure condition continues to have uncertainties that indicate a relisting is a serious possibility. Even with the known and anticipated future conservation benefits of the Range-Wide Plan and other conservation efforts, based on current information and for the reasons stated above and in the Service's declarations in support of the Rule 59(e) motion, the Service does not believe that the threats to the lesser prairie-chicken have been sufficiently reduced or eliminated such that there is no longer a serious possibility that the Service will relist the species on remand. Declaration of Jennifer Norris, Acting Service Assistant Regional Director, Southwest Region, ¶12 (attached as Exhibit 1).

In Plaintiffs' second supplemental filing, Plaintiffs provided additional information from WAFWA regarding the Range-Wide Plan, including a discussion of enrollment of focal and connectivity habitat. ECF No. 110-1. The Service has taken that information into account, and all other information on the Plan that WAFWA has provided to the Service. But for all of the reasons stated above, the Service continues to believe that the population remains very small and

[2] Rather, the Service's December 15 filing only stated that the Plan has not had substantial success in the enrollment of suitable focal and connectivity habitat – a fact that WAFWA does not dispute and that the Service observed months ago in its Rule 59(e) motion, without objection from Plaintiffs or WAFWA. ECF No. 107 at 3; ECF No. 95-1 ¶ 33.

fragmented, particularly in the ecoregion containing the Permian Basin, that conservation efforts have not yet sufficiently reduced or eliminated the threats to the species, and that there is more than a serious possilibity that it would return the species to the list of threatened and endangered species on remand. Norris Declaration ¶ 12. Plaintiffs and WAFWA have not shown otherwise. Indeed, Plaintiffs conceded that until the Service completes a new analysis, "no one knows whether the LPC is threatened." ECF No. 83 at 1 n.5. WAFWA stated after vacatur of the listing decision that the lesser prairie-chicken's population "is still low compared to historical numbers and the threats to the lesser prairie-chicken and its habitat still exist." See attached Exhibit 2 (emphasis added). For all of these reasons, remand without vacatur is appropriate.

II. Vacatur Is Disruptive Because It Allows Continued Destruction and Fragmentation of Habitat and Sets Back Voluntary Conservation Efforts

As we have explained in our prior filings, vacatur is disruptive and inequitable because it will accelerate the fragmentation and destruction of lesser prairie-chicken habitat, ultimately only making it more difficult to reach the point where the protections of the ESA are not necessary for this species. In two prior declarations, the Service identified several examples of signficant development in lesser prairie-chicken habitat that is likely to go forward. First Shaughnessy Declaration ¶ 19, 21; ECF No. 100-1 ("Second Shaughnessy Declaration") ¶ 3, 4. In their response to Plaintiffs' first supplemental filing, Defendants also have provided publicly available data confirming that such development is occurring, has already occurred, or is imminent. ECF No. 107 at 4-5. In addition, since the Service's previous two declarations to the Court, the Service has learned of several additional prospective wind projects in Oklahoma and Kansas that would occur in currently suitable habitat for the species. Norris Declaration ¶ 14(a). The Service has also recently confirmed, through a communication between a Service employee and the project consultant, that the dairy farm in Prowers County, Colorado – previously identified in Defendants' briefs as a prospective project in occupied lesser prairie-chicken habitat – in fact went forward, resulting in the removal or loss of that habitat for the species. Norris Declaration ¶ 14(b); First Shaughnessy Declaration ¶ 19(a).

In their second supplemental filing, Plaintiffs provided a statement from WAFWA that

"the argument and independent reports suggesting that development is imminent or occurring" in lesser prairie-chicken habitat are "speculative and/or misinformed." ECF No. 110-1 at 11. The Service disagrees. As an initial matter, the information provided by Plaintiffs from WAFWA regarding the alleged status of some of the wind energy projects identified by the Service is itself speculative, unsupported by any correspondence or declaration. Id. at 12. When discussing these projects, Plaintiffs' filing does not even refer to them by name or identify the developers providing the alleged information, making it difficult for the Service to respond, at best. Id.[3] And even if the developers of some of these projects now purport to tell WAFWA that they currently do not intend to go forward, there is nothing stopping them from changing their mind at any time and going forward without adequate protections for the species. That is what vacatur allows.

Late yesterday, the Service also received letters from the developers of two of the six wind energy projects that the Service identified in its prior declarations. The developers argue that their projects (the Roosevelt and Vici wind farms) pose no threat to the species and accuse the Service of providing "inaccurate" information. See attached Exhibit 3 ("Vici Letter") and Exhibit 4 ("Roosevelt Letter"). The Service strongly disputes that its concern regarding the impacts of these two projects on the species is misplaced. As the Vici wind farm developer shows in a map attached to its letter, the project extends into the area that represents the estimated range of the species plus a ten-mile buffer established by WAFWA. Vici Letter at Attachment A. WAFWA explained that it established this buffer because "[lesser prairie-

[3] For example, the statement by WAFWA alleges that "[t]wo of the companies referenced in the FWS filing informed WAFWA that they had consulted directly with the FWS on their projects" and speculates that "FWS may have not included additional communications with those companies and misrepresented the company's actions and intentions." ECF No. 110-1 at 12 (emphasis added). WAFWA has not named the projects or companies in question, let alone identified any specific alleged misrepresentation by the Service. The Service disputes that it has knowingly provided any inaccurate information regarding wind energy projects. As indicated in the attached declaration, the Service is aware of one wind energy project (the Roosevelt project) where correspondence from the company was not transmitted to the appropriate Service staff, leading to confusion regarding whether any active leks would be affected by construction. Following proper receipt of this communication, the Service is approaching the company to resolve the ambiguity. Norris Declaration ¶ 14(c). See also Exhibit 4 at Attachment A.

chickens] are currently recorded as much as 30 miles beyond the northern boundary of the historic range, and the current estimated occupied range varies from year to year as a function of shifting habitat, population size and detectability. We included the 10-mile buffer around the estimated occupied range to account for these sources of variability." See Administrative Record at F000275. The map provided by the Vici project developer also shows that the project is only about six miles from focal habitat identified by the Range-Wide Plan (Unit No. 12) and not much farther from connectivity habitat identified by the Plan (Unit No. 111). Vici Letter at Attachment A.[4] The map further shows that the project includes suitable habit for the species, identified by habitat modelling. Id.[5] Similarly, the developer of the Roosevelt project concedes that the project resulted in impacts on habitat for the species designated as CHAT 2 and 3 by WAFWA. Roosevelt Letter at 2. CHAT 2 is connectivity habitat, while CHAT 3 is suitable habitat within the occupied range. Administrative Record at F000303-04. The developer of the Roosevelt project also mistakenly assumes that the ESA only prohibits "take" of "individuals of the species," not "impacts to habitat." Id. Contrary to this flawed assumption, as we previously explained, the "take" prohibitions of the ESA do extend to habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding or sheltering, see 50 C.F.R. §17.3 and Babbitt v. Sweet Home Chapter of Cmtys. for a Great Or., 515 U.S. 687 (1995), and the Service protected against those impacts by listing of the lesser prairie-chicken. ECF No. 107 at 7.

The developers of the Roosevelt and Vici projects also have not obtained concurrence from the Service for their conclusions about impacts on the species or any measures taken to minimize impacts on the species. To the best of the Service's knowledge, the developer of the

[4] The Service originally stated that it believed the Vici project was "in or near" two other units of connectivity habitat (Unit Nos. 108 and 109). That is not inaccurate given that the project is only about 20-25 miles from those units. In any event, the project is even closer to two other units of equally important focal and connectivity habitat (Unit Nos. 12 and 111).

[5] The developer asserts that the habitat is "marginal," Vici Letter at 4, but much of the species' habitat is now marginal, i.e., fragmented, and what is needed for conservation of the species is restoration of precisely such habitat.

Vici project has had no communications with the Service prior to its January 26 letter, and instead concluded without any Service input that the species would not likely be impacted. While the developer of the Roosevelt project had some discussions with the Service, it admits that it located turbines using a buffer of only two miles from lesser prairie chicken lek sites, when the Service advised using three miles. See Roosevelt Letter at 3. The Service advises a buffer of three miles based on the scientific literature. See ECF No. 107 at 7, n.4 and Exhibit 9 at 1 (first sentence of the second paragraph). This demonstrates the Service's concern that with vacatur, there is no requirement for private developers to heed the Service's advice, enroll in the Service-approved Range-Wide Plan or, alternatively, undergo the more rigorous and thorough permit process available for listed species under ESA Section 10, in which the Service, with its biological expertise, determines what impacts exist and what protections are necessary for the conservation of the species. 16 U.S.C. § 1539. In the absence of listing, developers are free to "make their own calls," which are not necessarily based on a proper and full understanding of the science and law.[6]

The Service also disagrees with the claim that the wind energy projects identified by the Service would not have a "demonstrable impact" because they would cause only a small amount of habitat loss relative to the species' total range. ECF No. 110 at 12. Several of these projects are located in or near focal and connectivity habitat prioritized for protection by the Range-Wide Plan. Second Shaughnessy Declaration ¶ 3. Even if members of the species are not currently found in certain areas, suitable habitat that lies in close proximity to focal and connectivity habitat is important to the species. The species' numbers are very low and its habitat is already highly fragmented. First Shaughnessy Declaration ¶ 4, 26. On these facts, the loss and fragmentation of even relatively small amounts of existing and suitable habitat can easily put the

[6] In their letters, the developers fault the Service for not reaching out to them sufficiently, but they misapprehend how the ESA is intended to work. Were the species listed, developers would be required to adopt Service-approved conservation measures such as the Range-Wide Plan, or to proactively reach out to the Service and obtain any necessary individual ESA Section 10 permit for the activity. Listing puts the burden on the developer, which is another reason vacatur has such a negative real-world impact in this case.

species on a path towards a "death spiral" from which it cannot recover, as the Service has seen for similar prairie grouse species such as the now-extinct heath hen and endangered Attwater's prairie-chicken. Norris Declaration ¶ 6, n.1. See also First Shaughnessy Declaration ¶ 4 (stating that the species is "exceptionally vulnerable to small changes on the landscape, especially at its currently reduced numbers").

In any event, the Service's argument that vacatur is disruptive and inequitable goes far beyond the specific examples of wind energy development cited by the Service. The Service also identified ESA Section 7 consultations with other federal agencies regarding projects that affect lesser prairie-chickens and their habitat. First Shaughnessy Declaration ¶ 21. When a species is protected under the ESA as threatened or endangered, these consultations occur to ensure federal agency actions will not jeopardize the continued existence of the species or adversely modify or destroy its designated critical habitat. As the Service explained, consultations related to the lesser prairie-chicken are no longer going forward due to vacatur of the listing decision. Id. See also Norris Declaration ¶15. Indeed, the Service has learned that in Oklahoma alone, there are at least seven pending highway improvement projects with federal involvement in suitable lesser prairie-chicken habitat where the vacatur will prevent the Service from requiring appropriate mitigation measures as part of an ESA consultation. Norris Declaration ¶15(b). In addition, given that potential developers have no legal requirement to communicate with the Service in the absence of listing, there is every reason to believe that projects other than those known to the Service are proceeding without sufficient protections for the species. At the hearing, Plaintiffs themselves identified such protections as "injury" that some developers logically would seek to avoid unless required by listing. ECF No. 104 at 36.

Given the continuing poor status of the species and its fragmented habitat, any significant development without adequate protections for the species will ultimately set back conservation efforts. That is neither in the public interest nor consistent with the purposes of the ESA. Courts have recognized that remand without vacatur is appropriate in such circumstances. Davis Cnty. Solid Waste Mgmt. v. EPA, 108 F.3d 1454, 1459 (D.C. Cir. 1997) (denying vacatur where it was

"likely that [vacatur] . . . will result in significantly greater pollution emissions than would occur if these emission standards were not vacated."); Endangered Species Comm. of Bldg. Indus. Ass'n v. Babbitt, 852 F. Supp. 32, 42 (D.D.C. 1994) (denying vacatur of an ESA listing because of potentially irreparable harm to the public interest "if the Secretary's eventual decision is to continue the bird on the threatened species list.").

III. Conclusion

For the foregoing reasons and those set forth in our prior submissions, the Court should grant the Service's motion to amend the Court's judgment and remand the listing decision for the lesser prairie-chicken without vacatur. In light of the continuing poor status of the species and its habitat, the conservation efforts and their anticipated benefits have not yet reached the point where there is not a serious possibility of relisting the species on remand. With vacatur, development is continuing to occur in lesser prairie-chicken habitat without assurance of adequate protections for the species, worsening the species' already imperiled state and delaying the point where the protections of the ESA are not necessary for this species. A remand without vacatur would provide protections for the species during the remand.

Dated: January 27, 2016

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CERTIFICATE OF SERVICE

I hereby certify that on January 27, 2016, I electronically filed the foregoing with the Clerk of the Court using the CM/ECF system, which will send notification of this filing to the attorneys of record.

/s/ H. Hubert Yang
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Pit Pollution

— Backgrounder on the Issues, with a New Mexico Case Study —



Lisa Sumi
Oil and Gas Accountability Project
May, 2004

Pit Pollution

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1. Why Worry About Pits?

There are many fluids and wastes associated with oil and gas operations that can poison living organisms (e.g., cancer-causing substances such as benzene and other hydrocarbons; radioactive materials; heavy metals; and many others). When discharged into unlined pits the toxic substances in pits can leach directly into the soil and may contaminate groundwater. Lined pits can also lead to pollution via ruptures in liners or by overflowing the pit area. These events can result in soil and water contamination, which can have a negative effect on both human and ecosystem health. For example, the New Mexico Environmental Bureau, since its inception in the mid-1980s, has recorded more than 6,700 cases of oil and gas pits causing soil and water contamination in the state, with 557 of those cases resulting in groundwater contamination.[1]

Another issue related to pits concerns direct contamination of wildlife and livestock. In the arid western states, animals are drawn to pits that contain fluids. If pits are inadequately fenced and netted wildlife and livestock can access the pit contents. There have been many instances of bird, wildlife and livestock mortality resulting from drinking or simply coming in contact with the toxic fluids in pits.

The types of wastes stored in pits include: drilling wastes; produced water; and production fluids and wastes. At the present time, these wastes, known as exploration and production (E&P) wastes, are not technically considered hazardous by the federal government. This is because in the past Congress exempted E&P wastes from our nation's hazardous waste law, the *Resource Conservation and Recovery Act* (RCRA).[2] This exemption was granted despite the fact that toxic substances are contained in the wastes, and despite the countless examples of groundwater, surface water, air and soil contamination related to oil and gas activities.

1.1 How Pit Pollution Occurs

Pits are used to store a variety potentially toxic, as well as non-hazardous liquid and solid wastes associated with oil and gas development.

Solid wastes, if left on site, may contain toxic substances that can:

1) Leach out of the solids and contaminate groundwater.
2) Contaminate soils and vegetation.
3) Sterilize soils and prevent vegetative growth.

Liquid wastes may contain toxic substances that can:

1) Overflow the sides of the pit (e.g., during a rain event, or due to inadequate storage volume of the pit) and pollute soil and surface waters.
2) Leach directly into the ground (if stored in unlined pits) and contaminate soil and water.
3) Seep into the ground (even if the pits are lined) through tears in liners, allowing substances to leak through to the soil and groundwater. Even if pits are lined, the liners are often improperly installed, or are torn, and frequently leak.

---

[1] Letter from Roger C. Anderson, Environmental Bureau Chief, New Mexico Energy, Minerals and Natural Resrouces Department, to Jennifer Goldman, OGAP. Oct. 23, 2003.

[2] U.S. Environmental Protection Agency. Oct. 2002. *Exemption of Oil and Gas Exploration and Production Wastes from Federal Hazardous Waste Regulations.* www.epa.gov/epaoswer/other/**oil**/**oil-gas**.pdf



Photo of pit with a torn liner.

1.2 Soil and Water Contamination from Pits

As mentioned in the section on New Mexico Oil and Gas Pits, there are 6,700 documented cases of groundwater and soil pollution from oil and gas pits in the state.

The City of Lovington, New Mexico, has experienced soil pollution from oil spills and pits. In recognition of the contamination threats posed by oil and gas drilling wastes, and in an effort to protect its municipal water supply, Lovington recently banned the use of drilling pits on the city's water field. Information on Lovington situation can be found in Press Clips, in Appendix I.

Soil contamination from pit pollution can inhibit the health and growth of vegetation on-site, which may lead to soil instability and erosion. Also, vegetation may uptake the contaminants and cause health problems for animals that eat the contaminated plants. Similarly, if the contaminants enter surface or groundwater, organisms (humans, livestock, wildlife, aquatic life, micro-organisms) drinking or living in the water may experience negative health effects or death, depending on the level of contamination.

Between 1996 and 2002, the U.S. Environmental Protection Agency (EPA) in Wyoming, Utah, Colorado, Montana, South Dakota and North Dakota conducted 475 field inspections at sites having one or more production pits or commercial facilities using disposal pits. [3]

Problems were found at 290 (more than 60%) of the sites. Issues of concern included:

- Ongoing discharges to surface and groundwater were documented at 22 % of the sites inspected, and those discharges were unpermitted at 35 of those sites (34% of the sites with ongoing discharges observed).
- Leaks and spills were observed from equipment.
- Secondary containment for oil storage tanks was inadequate or non-existent at many sites.
- Pits were improperly designed, located, and operated (including exposed oil on pits)
- Half of the pits observed were either entirely or partially covered in oil. In EPA's view, the number of sites with exposed oil on pits and bird mortality was higher than expected given that advance notice of inspections was provided to site operators.
- There were a number of bird and wildlife deaths related to the pits (142 birds, 42 wildlife).
- There were ineffective or non-existent wildlife exclusion devices at the sites.

[3] United States Environmental Protection Agency, Region 8. January 2003. *Oil and Gas Environmental Assessment Effort – 1996 – 2002.* http://www.epa.gov/region8/land_waste/ogeafinalreport.pdf

One key finding of the EPA report was that almost every commercial facility evaluated had significant environmental issues. Commercial oilfield waste disposal facilities are facilities that receive produced water and other exploration and production wastes for treatment and disposal. Pits, also known as surface impoundments or ponds, are used to holds wastes so that the liquids will evaporate off of the solid waste materials.

1.3 Wildlife and Livestock Mortality Related to Pits

The U.S. Fish and Wildlife Service (FWS) has documented numerous problems related to contaminants in oil field waste pits. In Wyoming, the U.S. Fish and Wildlife Service has found deer, pronghorn, waterfowl, songbirds and rabbits in oil pits. Even if animals are not killed in the pits, the oil and chemicals in the pits may affect their health. For example, if animals absorb or ingest oil, they may become more susceptible to disease and predation.[4]

The U.S. FWS web site contains information on *Contaminant Issues - Oil Field Waste Pits.* [5] This web site lists numerous wildlife-related problems associated with oil and gas pits, such as:

- Skim ponds are a fatal attraction to migratory birds
- Birds, bats and other wildlife mistake pits for wetlands
- Birds landing on waste pits can get covered with oil
- Oil can weigh birds down and cause them to drown
- Many bird deaths go undetected because the carcasses sink to the bottom of the pits
- Oil destroys the feathers' ability to insulate the birds resulting in death from heat or cold stress
- Even a light sheen on the water surface can be deadly. Oil on the feathers of female birds can be transferred to their eggs back at the nest, killing the embryo. Small amounts of oil applied externally to an egg shell can be extremely toxic to embryos
- Some birds become victims of pits when they feed on insects trapped in oil covering the surface of the water
- Animals scavenging on dead birds at these pits often succumb to the toxic effects of oil

Examples of Wildlife and Livestock Deaths from Pit Pollution

> **Chris Velasquez, Rancher - Blanco, New Mexico** (Excerpt from *A High Price to Pay*)[6]
> "I have complained repeatedly to BLM [Bureau of Land Management] about a shallow pit filled with "black gunk" near a gas well operated by Williams. The pit was on my grazing lease and I found cattle tracks to the pit and feared animals might be drinking the oily water. I've found dead cows near oil pits before, and seen lots of dead birds and other wildlife floating in the oil pits so I was worried this cow would drink out of the pit and die too. I lose eight to ten cows each year because of the oil field activity."

[4] U.S. Fish and Wildlife Service. *Wildlife Mortality Risk in Oil Field Waste Pits.* http://mountain-prairie.fws.gov/contaminants/papers/pitrisk.pdf
[5] U.S. Fish and Wildlife Service. Region 6, Environmental Contaminants. *Contaminants Issues - Oil Field Waste Pits*. http://mountain-prairie.fws.gov/contaminants/oilpits.htm
[6] San Juan Citizens Alliance and New Mexico Wilderness Alliance. *A High Price to Pay: Consequences of oil and gas production.* "Chris Velasquez, Blanco Rancher." http://www.oteromesa.org/people_velasquez.htm

Eliminating Oil Field Hazards (Excerpt from U.S. Fish and Wildlife Service, *Division of Law Enforcement, Annual Report 2001*)[7]
"Service special agents continued to conduct oilfield task force operations throughout historic petroleum production areas in New Mexico, Oklahoma, and Texas. In New Mexico, special agents conducted ground inspections of oil pits in Sandoval, Rio Arriba, and San Juan Counties in April 2001. Netting violations detected at eight production sites were referred to the New Mexico Oil Conservation Division for State follow-up. In August, oil field inspections in the southeastern part of the State documented multiple hazards and recovered 17 oil-covered birds; seven operators paid $6,425 in fines for violating the *Migratory Bird Treaty Act*. Dead birds were also discovered at several sites on Bureau of Land Management property in the State; the companies holding the oil leases paid over $8,000 in fines."

Regional Task Force Continues to Address Open Oil Field Pits and Tanks (Excerpt from *The Federal Wildlife Officer*, Spring 2002)[8]
"Service Special Agents throughout the region continued to investigate oil field pollution impacting migratory birds and other wildlife on historic oil fields in Oklahoma, Texas, and New Mexico. Three task force inspection operations were recently culminated following joint inspections of problematic well sites "Oil" and "G" initially documented by aerial surveillance. The Central Oklahoma operation resulted in the recovery of 32 oil covered migratory songbird and raptor carcasses from open pits or tanks operated by seven oil companies and the assessment of collateral fines totaling $11,900."

Is it possible to keep wildlife and livestock out of pits?

Measures to protect wildlife and livestock from toxic substances in pits include:
- systems to prevent oil from entering waste pits;
- immediately cleaning up any oil spills that find their way in open pits;
- adequate fencing around waste pits;
- netting to keep birds from entering pits.

Unfortunately, the devices used to keep out livestock and wildlife out of pits are often inadequate. For example, if netting is not installed properly or maintained well enough (e.g., if there are tears in the netting or if it sags into the waste pit, which is common after it snows), birds are still able to access the pits. Nets should be installed four or five feet above the pits to allow for sagging. Similarly, fencing can be used, but often, wildlife and livestock can still access pit areas.

1.4 Toxic Materials Stored and Disposed of in Pits

There are a variety of toxic substances utilized and created during the oil and gas extraction process. Yet "drilling fluids, produced water, and other wastes associated with the exploration,

[7] U.S. Fish and Wildlife Service. 2001. *Division of Law Enforcement, Annual Report 2001*. http://www.le.fws.gov/pdffiles/USFWS LAW92002.pdf
[8] The Federal Wildlife Officer Association Inc. 2002. "Regional Task Force Continues to Address Open Oil Field Pits and Tanks." *The Federal Wildlife Officer*. Volume 15, Number 1, Spring 2002. p. 2. http://www.fwoa.org/news/fwoanws27b.html

development, or production of crude oil or natural gas. . . " are not subject to federal hazardous waste law (*Resource Conservation and Recovery Act* (RCRA).

This exemption was granted despite the fact that toxic substances are contained in the wastes, and the fact that contamination of groundwater, surface water, air and soil have occurred and continue to occur from oil and gas activities. Even the U.S. Environmental Protection Agency acknowledges that although these oil and gas wastes are exempt from hazardous wastes regulations, the exemption does not mean these wastes could not present a hazard to human health and the environment if improperly managed.[9] Yet the exemption persists.

Potentially hazardous oil and gas wastes that may be found in pits.[10]

	Benzene (mg/l)	**Arsenic** (mg/l)	**Barium** (mg/l)	**Cadmium** (mg/l)	**Chromium** (mg/l)	**Lead** (mg/l)	**Selenium** (mg/l)
It should be considered a hazardous waste if it is above:	**0.5**	**5**	**100**	**1**	**5**	**5**	**1**
Production pit sludges	24					18.3	1.59
Production sands/solids	2,500	9.9			5.98		4.11
Workover/completion fluids	1,530	Heavy metals were not analyzed					
Produced formation – fresh water	1.3		646				
Produced formation – salt water	543		372	27.8	7.25	14.4	2.83
Oil-based drilling muds/cuttings	293	6.5	101	18.8		12.6	
Water-based drilling muds/cuttings	1,100	Heavy metals were not analyzed					

Drilling Fluids and Wastes

Drilling muds (also known as drilling fluids) are used to lubricate the drill bit and carry the rock cuttings back to the surface. Muds may be water-based, oil-based, or synthetic-based depending upon the drilling conditions encountered. Oil-based muds are the most toxic, followed by synthetic and then water-based muds.

Reserve pits are used to temporarily store the drilling muds during the drilling operations, and may be used to dispose of drilling wastes. When drilling is completed, reserve pits are usually closed, and:

- liquids in the pits may be evaporated, discharged to land or surface waters, reinjected in underground wells, or trucked off site for disposal.
- solids in the pits may be spread on land, buried on-site or trucked to an off-site disposal area.

Drilling wastes may contain an array of potential toxic substances.
A survey conducted by the U.S. Environmental Protection Agency and the American Petroleum Institute found that liquids in some drilling reserve pits contained: chromium, lead and pentachlorophenol at hazardous levels, and that oil-based fluids may contain benzene.[11] If improperly disposed of, these fluids can contaminate groundwater, surface waters and soil.

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[9] U.S. Environmental Protection Agency. Oct. 2002. *Exemption of Oil and Gas Exploration and Production Wastes from Federal Hazardous Waste Regulations.*
www.epa.gov/epaoswer/other/**oil**/**oil-gas**.pdf
[10] Subra Company. 2003.
[11] U.S. Congress, Office of Technology Assessment. March, 1992. *Managing Industrial Solid Wastes from Manufacturing, Mining, Oil and Gas Production, and Utility Coal Combustion – Background Paper, OTA-BP-O-82.* (Washington, DC: U.S. Gov. Printing Office). p. 75

1) The drill cuttings that are brought to the surface (i.e., fragments of rock removed from the bore hole) contain varying amounts of hydrocarbons (oil, gas, volatile organic compounds such as benzene).

2) Drilling muds that circulate through the well and return to the surface may contain potentially hazardous substances including a variety of metals (cadmium, arsenic, chromium, lead, mercury, copper, etc.); diesel oil; grease; and various other hydrocarbons and organic compounds (e.g., methanol, chlorinated phenols, formaldehyde, benzene, toluene, ethyl benzene, xylene and acrylamide). Typically, if oil-based muds are used, there will be higher quantities of potentially toxic hydrocarbons such as benzenes and polycyclic aromatic hydrocarbons (PAHs), both of which are known to cause cancer in humans. But as seen in the table above, Subra Company found that both oil- and water-based drilling cuttings and muds can contain benzene at extremely high levels (see the table above).

3) Drilling muds often contain bentonite clay and other additives. Bentonite is a very expansive soil material. This may create a site with the potential for great soil volume change, and possibly damage to surface structures. The common practice for disposing of drilling muds is to either bury the mud reserve pit, or discharge the mud to the surface. For landowners who may want to build on what was previously a drill site, it is worth noting that in order to be eligible for FHA mortgage insurance, all unstable and toxic materials must be removed and the pit must be filled with compacted selected materials.[12]

4) Drilling mud reserve pits may also contain a mixture of other additives and chemicals that are used during the drilling process. These may include:
   - acids and caustics;
   - corrosion inhibitors (e.g., iron oxide, aluminum bisulfate, zinc carbonate, and zinc chromate)
   - bactericides and biocides (typically organic amines, chlorophenols, or formaldehydes)
   - surfactants, defoamers and emulsifiers (e.g., fatty acids and soaps)
   - filtrate reducers;
   - shale control inhibitors;
   - thinners and dispersants (e.g., iron lignosulfonates)
   - weighting materials (e.g., barium sulfate, barite or hematite);
   - lost-circulation materials
   - bentonite clay
   - flocculants (e.g., acrylic polymers such as acrylamide)

   Drilling additives often contain potentially toxic substances. For example, the EPA has classifed the flocculant acrylamide as a probable carcinogen.[13] Also, barite weighting agents may contain concentrations of heavy metals such as cadmium or mercury.[14] It is often difficult, however, to find detailed information on the exact chemical composition of drilling additives, as the mix of substances is considered *proprietary* information.

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[12] U.S. Department of Housing and Urban Development. Directive No. 4150.2. *Valuation Analysis for Single Family One- to Four- Unit Dwellings.*

[13] U.S. Environmental Protection Agency. Technology Transfer Air Toxics Web site. "Acrylamide" http://www.epa.gov/ttnatw01/hlthef/acrylami.html

[14] Railroad Commission of Texas. Oil and Gas Division. *Waste Minimization in Drilling Operations.* www.rrc.state.tx.us/divisions/og/key-programs/ogkwodoc.html

Consequently, companies are able to hide the potentially toxic ingredients from concerned citizens.

An example of how companies can withhold information comes from a report written on offshore oilfield drilling wastes and disposal techniques.[15] The report documents how one company legally dumped 896 tonnes of drilling muds off the coast of Great Britain. When questioned about the constituents in the drilling mud, both the company and the government body overseeing the industry would provide only the trade names of the chemicals. The company described one drilling additive, SOLTEX® (trade name for a shale control inhibitor used in water-, oil- or synthetic-based muds, in both on-shore and offshore drilling operations[16]), as lignite (non-asphaltic), and further described it as "cellulose-based," with no reference to the fact that it contains potentially toxic heavy metals.[17]

In 1995 Greenpeace published the following typical analysis for heavy metal content of SOLTEX®, which they obtained from "a confidential source".[18]

Components of SOLTEX®	**Concentration (mg/kg)**
Antimony	6.0
Arsenic	0.4
Barium	16.0
Cadmium	0.6
Chromium (total)	1.2
Cobalt	2.0
Copper	1.3
Fluoride	200.0
Lead	3.0
Mercury	0.2
Nickel	11.0
Vanadium	16.0
Zinc	2.1

Whether or not drilling additives cause harm in the environment depends on the amount of additive used, the concentrations of potentially harmful constituents, and how quickly (if at all) the toxic substances break down once they enter the environment.

Without full disclosure of chemical constituents, however, the public has no way of gauging the potential hazards posed by drilling muds and additives.

[15] Jonathan Wills, M.A., Ph.D. May 2000. *Muddied Waters. A Survey of Offshore Oilfield Drilling Wastes and Disposal Techniques to Reduce the Ecological Impact of Sea Dumping.* http://www.offshore-environment.com/additives.html
[16] http://www.cpchem.com/drillingspecialties/products/soltex.asp
[17] Reddy, S., et al. 1995. cited in *Muddied Waters.*
[18] Jonathan Wills, M.A., Ph.D. May 2000. *Muddied Waters. A Survey of Offshore Oilfield Drilling Wastes and Disposal Techniques to Reduce the Ecological Impact of Sea Dumping.* http://www.offshore-environment.com/additives.html

Less toxic alternatives exist

Substitutions of some drilling-related chemicals can minimize the toxicity of drilling wastes and reduce the risks and costs associated with drilling fluid disposal. According to the U.S. Environmental Protection Agency, there are less toxic alternatives to some of the more toxic compounds. Unfortunately, many companies continue to use the more toxic substances.

Less toxic alternatives include:[19]

- **Dispersants:** use of chrome-free lignosulfonates and polysaccharide polymers instead of chrome lignosulfonate.
- **Biocides:** use of amines instead of pentachlorophenols and paraformaldehyde.
- **Drilling fluid lubricants:** use mineral oil and lubra-beads instead of diesel oil.

Produced Water

When drilling takes place, water is often encountered in along with the oil and gas. This water is pumped out with the oil and gas, and is separated from it using equipment at the surface. In coalbed methane (CBM) operations, huge volumes of produced water are generated because removal of the water is what allows the gas to flow out of the coal.

Produced water may be stored on the surface in open pits, which are also referred to as evaporation pits or disposal pits.

Most contaminants found in produced water are naturally occurring, and so they will vary based on what is present in the subsurface at a particular location. In some locations, the water removed is extremely salty. If the produced water contains large quantities of salts, it is typically referred to as brine or salt water. Other constituents often found in produced water include:

- volatile organic compounds (VOCs) – e.g., benzene, toluene, ethyl benzene, xylene
- polycyclic aromatic hydrocarbons (PAHs) – e.g., naphthalene
- other hydrocarbons, such as crude oil
- heavy metals – e.g., arsenic, barium, cadmium, chromium, lead, mercury, selenium, vanadium, zinc
- Naturally Occurring Radioactive Materials (NORM) – Radium 226 or 228

There are a number of problems that can arise if produced water contaminates soil or groundwater, or if produced water is stored in a manner that allows it to be accessible to livestock, wildlife and birds. Potential problems include:

- Excess salts can effectively sterilize soils for years
- Some metals and NORM can be taken up by vegetation, and pose a health threat to animals that consume the plants; and these substances can be toxic to wildlife that drink the produced water
- Hydrocarbons, benzene and PAHs can contaminate soil and water. Health effects associated with hydrocarbons include: respiratory ailments, effects on neurologic, cardiac and gastrointestinal systems, and skin disorders. Some hydrocarbons are known to cause cancer (e.g., PAHs and benzene). The amount of exposure and how the exposure occurs (e.g., skin contact, ingestion, inhalation) influence which bodily systems are affected the extent of damage to the systems.

[19] U.S. Environmental Protection Agency (U.S. EPA). October 2000. *Profile of the Oil and Gas Extraction Industry.* EPA Office of Compliance Sector Notebook Project. EPA/310-R-99-006. p. 70.

Production Fluids and Wastes

Numerous pits may be used to store or dispose of fluids produced during the production stage of oil and gas operations.

Oil/hydrocarbon production pits: In many oil and gas extraction operations, water, oil and various natural gases are simultaneously extracted. Separators are used to separate the oil from the natural gases, and a "heater treater" separates the water from the oil. According to the U.S. Fish and Wildlife Service, this process is often ineffective.[20] As a result, oil and other hydrocarbons are mixed in with the waste water; and this oily water may be sent to disposal pits. Oil- or hydrocarbon-laden produced water, if stored in open pits, presents a hazard to birds, livestock and wildlife.

Dehydrator waste production pits: natural gas from conventional natural gas wells and coalbed methane wells often contains water, which must be removed before the methane gas can be sold. Much of the waste water is released as vapor, but a significant amount of vapor condenses back into water, which is stored or disposed of in tanks or open pits, sometimes referred to as "drip pits."

There are several processes that can be used to remove water from the gas. These include: glycol dehydration; solid desiccant dehydration; and calcium chloride dehydration.

According to a report by the U.S. EPA, [21] the waste water from dehydration processes may contain:

- Dissolved hydrocarbons, including BTEX (benzene, toluene, ethylbenzene and xylene). Benzene is a known human carcingen.
- metals such as arsenic, barium, cadmium, chromium and lead.

Workover fluids: during well workover operations, which are the major maintenance and equipment repairs done on wells, chemicals, some of which are toxic, are used. These chemicals usually appear in the produced water when production resumes,[22] or in the case of cleaning fluids, may be spilled from equipment at the surface.

Examples of potentially toxic workover fluids include:[23]

- Scale removal requires strong acids, such as hydrochloric or hydrofluoric acids. Scale itself is primarily comprised of sodium, calcium, chloride and carbonate; but trace contaminants such as barium, strontium, and radium may be present.
- Corrosion inhibitors are flushed through the well. Corrosion-resistant compounds of concern include zinc carbonate and aluminum bisulfate.
- In addition, painting- and cleaning-related wastes, such as solvents containing suspended oil and grease, may be generated during workovers.

Stimulation/Completion fluids: Stimulation fluids may also be known as completion fluids. These fluids are injected into a well to encourage the flow of oil and gas to the surface. One common stimulation practice, known as hydraulic fracturing or "fracing," involves injecting a highly

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[20] U.S. Fish and Wildlife Service. Region 6, Environmental Contaminants. *Contaminants Issues - Oil Field Waste Pits*. http://mountain-prairie.fws.gov/contaminants/oilpits.htm

[21] U.S. Environmental Protection Agency. January, 2000. *Associated Waste Report: Dehydration and Sweetening Wastes.* p. 18 http://www.epa.gov/epaoswer/other/oil/execrep.htm

[22] U.S. Environmental Protection Agency. January, 2000. *Associated Waste Report: Completion and Workover Wastes*. p. 38. http://www.epa.gov/epaoswer/other/oil/execrep.htm

[23] U.S. Environmental Protection Agency (U.S. EPA). October 2000. *Profile of the Oil and Gas Extraction Industry.* EPA Office of Compliance Sector Notebook Project. EPA/310-R-99-006. p. 41.

pressurized solution of solvents and gelling agents, mixed with sand and water, into the underground geologic formation to create and hold open fractures. A single oil or gas well can require several "frac-jobs" or other stimulation efforts to compete its total production, and will utilize up to five pits to manage its wastes during its total lifecycle.

Another stimulating technique is acidizing, which involves pumping acid (usually hydrochloric acid), into the formation. The acid dissolves some of the rock material so that the rock pores open and fluid flows more quickly into the well. Fracing and acidizing are sometimes performed simultaneously, in an acid fracture treatment.

Stimulation fluids may contain toxic, hazardous and carcinogenic materials including: benzene, polycyclic aromatic hydrocarbons, ethylbenzene, toluene, xylene, naphthalene, methanol, sodium hydrozide, and methyl tertiary-butyl ether (MTBE),[24] as well as a variety of metals (e.g., antimony, barium, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, sliver, thallium, vanadium and zinc).[25] Very small quantities of chemicals such as benzene are capable of contaminating millions of gallons of water. And only 28 tablespoons of MTBE could contaminate hundreds of thousands of gallons of groundwater, making that water unfit for human consumption.[26]

In 1992, the U.S. EPA conducted a sampling program to characterize the potentially hazardous compounds in workover and completion wastes.[27] They collected seven workover and completion samples from oil and gas sites in New Mexico, Oklahoma and Texas. Several of the samples were taken after fracturing and acidizing had occurred. The other samples were taken during swabbing of a pipeline, and after completion of an injection well. More than 70 elements and chemicals were found in the samples, although there was a wide range in concentrations in the samples. Six of the seven samples exhibited hazardous characteristics of toxicity for benzene. Toluene and lead also appeared at toxic levels in some of the samples.

2. Alternatives to Pits

2.1 Alternative to Unlined Pits

If pits are used, they should have, at minimum, two layers of liners, with a leak detection system between the layers. Furthermore, pits should have fences tall and strong enough to keep out wildlife, and nets or other devices installed to prevent birds from coming in contact with the wastes.

But there are alternatives to using lined or unlined pits. Steel tanks, ideally with secondary containment and leak detectors, can be used to store many oil and gas wastes during operations. The wastes can then be transported off site for permanent disposal.

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[24] U.S. Environmental Protection Agency. August, 2002. *DRAFT Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs*. EPA 816-D-02-006. Chapter 6. Water Quality Incidents. http://www.epa.gov/safewater/uic/cbmstudy/docs.html

[25] U.S. Environmental Protection Agency. January, 2000. *Associated Waste Report: Completion and Workover Wastes*. pp. 56-57. http://www.epa.gov/epaoswer/other/oil/execrep.htm

[26] Johnson, R., et al., "MTBE: To What Extent Will Past Releases Contaminate Community Water Supply Wells?," Environ. Sci. Technol. 2000, 34 (9), 210 A-217 A. Cited in Natural Resources Defense Council. January, 2002. "Hydraulic Fracturing: A threat to drinking water."

[27] U.S. Environmental Protection Agency. January, 2000. *Associated Waste Report: Completion and Workover Wastes*. pp. 66-73. http://www.epa.gov/epaoswer/other/oil/execrep.htm

During drilling operations, "closed-loop" drilling fluid systems (sometimes referred to as closed mud systems) can greatly reduce or eliminate the discharge of toxic drilling wastes on site. These systems negate the need for drilling reserve pits. Not only is it possible to have "pitless" drilling operations, it can also be an economic advantage to companies to used closed-loop drilling systems.

Many companies are using closed loop drilling systems in Texas, Louisiana, Oklahoma, Alaska and other states. Examples of companies who are using closed-loop technologies include: Shell, El Paso, Chevron-Texaco, Exxon, and many others.

2.2 Closed Containment Systems

Oil and gas operators can use closed containment systems (e.g., tanks that are not open on top) in place of various production pits. It is important that tanks be enclosed by fences and nets. Otherwise, birds, wildlife and livestock may still be attracted to the liquid in the tanks.[28]



Photo of a closed containment system in New Mexico.

This tank has a steel-mesh lid to keep out wildlife and birds. The secondary containment pit has prevented the fluids from flowing all over the well site, but it is clear that the waste fluids have seeped into the surrounding soil. It is not clear whether or not contamination of groundwater has occurred. These wastes, which may contain toxic chemicals, are now accessible to wildlife.

Tanks do have a tendency to corrode with time and develop leaks. And they may overflow if their capacity is not adequate to hold the wastes (and any precipitation if the tanks are not enclosed).

The New Mexico Oil and Conservation Division's document ***Pollution Prevention Best Management Practices for the New Mexico Oil and Gas Industry*** suggests the following measures to prevent contamination from tanks.[29]

- All above ground tanks that contain fluids other than fresh water must be contained in an impermeable bermed enclosure to contain a volume of one-third more than the total volume of the largest tank or of all interconnected tanks.
- All below grade tanks. . . must have secondary containment and leak detection.

[28] http://mountain-prairie.fws.gov/contaminants/contaminants1c.html

[29] **Pollution Prevention Best Management Practices for the New Mexico Oil and Gas Industry**, Volume I, Section 6, pp. 49, 50. http://www.emnrd.state.nm.us/ocd/

Benefits of closed containment systems

- Tanks require little or no maintenance
- Tanks may be reused (moved to a new site) when the well stops producing.
- Tanks isolate waste products from the environment; if enclosed tanks are installed, there is no need to install fences or netting to keep out wildlife and livestock
- These systems greatly reduce or eliminate soil contamination, thereby reducing remediation costs.

Examples of closed containment systems

- In 2003, the Farmington, New Mexico City Council approved five gas wells on the condition that the company agreed to store condensate wastes in buried tanks; and install double walled condensate tanks as a means of leak protection.[30]
- Many well sites in New Mexico used tanks, rather than pits, to hold production wastes. What's missing from many of the tanks in New Mexico are leak detection devices and adequate secondary containment systems.

2.3 Closed-loop or "Pitless" Drilling Systems

What's the difference between conventional drilling systems and closed-loop drilling systems?
At a typical oil or gas drilling site, drilling fluids (mud, water, additives) are circulated through the wellbore, then the fluids and drill cuttings (rock fragments created by the drilling process) are deposited in a reserve pit dug near well. This pit is used to hold used drilling fluids and wastes.

A reserve pit can be the source of considerable costs at a drilling site. The pit itself must be constructed at the beginning of drilling, which requires the use of heavy earthmoving equipment. The pit may have to be lined, which is an added expense. And when the drilling project is over, the pit, including all of the waste fluids and solids, must be properly remediated. Remediation could include activities such as: the removal and offsite disposal of the waste materials and liner; the burial of the wastes and liner; backfilling of the pit with soil; and revegetation of the disturbed pit area.

In a closed-loop drilling fluid system, the reserve pit is replaced with a series of storage tanks that separate liquids and solids. Equipment to separate out solids (e.g., screen shakers, hydrocyclones, centrifuges) and collection equipment (e.g., vacuum trucks, shale barges) minimize the amount of drilling waste muds and cuttings that require disposal, and maximize the amount of drilling fluid recycled and reused in the drilling process. The wastes created are typically transferred off-site for disposal at injection wells or oilfield waste disposal facilities.

Increased Utilization of Closed-Loop Drilling

According to a paper delivered at an American Association of Drilling Engineers Conference in 2002, "environmental concerns and regulatory authorities are forcing the offshore drilling industry to modify or eliminate dumping of drilling wastes overboard. On land rigs, the practice of constructing earthen reserve pits is also declining in favor of "zero-discharge" closed-loop systems. Therefore the effective containment and transportation of drilling wastes is becoming

[30] Laura Banish. February 12, 2003. "Farmington council approves five new gas wells," *Daily Times* Farmington, New Mexico).

ever more important. The environmental benefits of a well designed waste collection and transportation system can be observed directly in many cases."[31]
The New Mexico Oil Conservation Division identifies closed-loop drilling as a "best management practice" in their Pollution Prevention Best Management Practices for the New Mexico Oil and Gas Industry. New Mexico OCD is not alone in identifying closed-loop drilling systems as a "best practice." In almost any pollution prevention or "Best Management Practices" document for the oil and gas industry, closed-loop drilling systems are mentioned as the most environmentally safe method for reducing the potential impact that drilling operations can have on the environment.[32]

Increasingly, closed loop systems are being used all over the United States, Canada, and the world. In personal conversations with closed-loop drilling system companies, OGAP has heard that one company has performed approximately 900 closed-loop drilling operations in the past 8 years (in CO, WY, ND, NM and other western states). A representative from another company operating out of Texas, Louisiana and Oklahoma remarked that most of the major companies in the region are using closed-loop drilling systems at the majority of their operations, because they understand the potential future liabilities that may follow them if they use conventional drilling systems that use reserve pits.

This information was corroborated by the Texas Railroad Commission, which stated that "Even though it is not always cost effective, some companies have elected to use only closed loop drilling fluid systems in their operations. . .whenever a closed-loop system is used, the operator reduced his potential liability associated with a conventional earthen pit and waste management and site closure costs." [33]

According to the U.S. Congress, Office of Technology Assessment, these systems are increasingly being used (e.g., in California) because of the reduction in overall drilling costs and in the volume of wastes needing disposal.[34]

Benefits of Closed-Loop Drilling

Efficient use and re-use of materials
The tanks represent an additional cost, but there is no longer a need to construct the reserve pit. The tanks can be re-used, and there is a reduction the risk of environmental contamination. Additionally, there is a more efficient use of drilling fluid, and the technology can save the operator money when conditions allow its use.[35]

According to the Railroad Commission of Texas' Oil and Gas Division:

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[31] Richards, M.J. and Love, W.W. 2002. "Bulk Transportation of Drilling Waste," a paper presented at the American Association of Drilling Engineers 2002 Technology Conference, April 2002, in Houston, TX. Paper AADE-O2-DFWM-HO-18.
[32] E.g., The Illinois Environmental Protection Agency's "Best Management Practices for Oil Exploration and Extraction." (http://www.epa.state.il.us/p2/fact-sheets/bmp-oil-exploration.html). And the Railroad Commission of Texas' "Waste Minimization in Drilling Operations." www.rrc.state.tx.us/divisions/og/key-programs/ogkwodoc.html
[33] Railroad Commission of Texas. Oil and Gas Division. Waste Minimization in Drilling Operations. www.rrc.state.tx.us/divisions/og/key-programs/ogkwodoc.html
[34] U.S. Congress, Office of Technology Assessment. March, 1992. *Managing Industrial Solid Wastes from Manufacturing, Mining, Oil and Gas Production, and Utility Coal Combustion – Background Paper, OTA-BP-O-82.* (Washington, DC: U.S. Gov. Printing Office). p. 75
[35] U.S. Environmental Protection Agency (U.S. EPA). October 2000. *Profile of the Oil and Gas Extraction Industry.* EPA Office of Compliance Sector Notebook Project. EPA/310-R-99-006. p. 69.

Closed-loop drilling fluids systems use a series of steel tanks that contain drilling fluids and equipment used to remove cuttings. These systems enhance the operator's ability to monitor fluid levels and characteristics. The result is more efficient use of the drilling fluid and less drilling waste remaining at the end of the operation. Also, the operator may more easily recycle the waste drilling fluid.[36]

Closed-loop systems reduce company liability

Pits may or may not be lined (depending on the oil and gas regulations); and pits are open to the atmosphere. Because of this, the pit may leak liquids into surface or groundwater and release high levels of volatile organic compounds, which in turn create health, environmental, and financial risks. If improperly fenced, livestock may enter the pit area. If the livestock is poisoned by the pit materials, companies may be liable for the deaths, and be required to compensate the livestock owner.

According to the Railroad Commission of Texas, even though closed-loop drilling is not always the least expensive option, some companies in Texas have elected to use only closed-loop drilling fluids systems in their operations. Why? Because whenever a closed-loop system is used, the operator reduces the potential future liability associated with a conventional earthen pit, and reduces the waste management and site closure costs. It's also good for the company image and public relations.[37]

Closed-loop or pitless drilling also:

- eliminates unsightly and hazardous pits
- reduces the time, energy and expense of building, fencing and netting, and reclaiming reserve pits
- decreases the need for cuts in sensitive and hilly areas
- total surface disturbance associated with a well pad is reduced
- eliminates risk of waterfowl and wildlife mortality related to pits
- eliminates risk of damaging underground pipelines and utilities
- allows drilling in areas with a high ground water table (e.g., floodplains)
- greatly reduces drilling wastes (even drill cuttings may be put to beneficial use, e.g., if not contaminated they may provide a source of finely-ground clay for berm construction around tank batteries or other uses)
- rigs use less water per well—it can reduce water consumption by as much as 80%
- the US Environmental Protection Agency (EPA) has estimated that "closed loop systems" can reduce the volume of drilling fluids by as much as 90%[38]
- eliminates soil segregation, which reduces wind erosion problems and costs associated with soil moving
- reduces truck traffic associated with transporting drilling wastes by as much as 75%
- may improve relationship with surface owners
- greatly reduces waste tracking and need for land farming operations

[36] Railroad Commission of Texas. Oil and Gas Division. Waste Minimization in Drilling Operations. www.rrc.state.tx.us/divisions/og/key-programs/ogkwodoc.html

[37] Railroad Commission of Texas. Oil and Gas Division. Waste Minimization in Drilling Operations. www.rrc.state.tx.us/divisions/og/key-programs/ogkwodoc.html

[38] U.S. Congress, Office of Technology Assessment. March, 1992. *Managing Industrial Solid Wastes from Manufacturing, Mining, Oil and Gas Production, and Utility Coal Combustion – Background Paper, OTA-BP-O-82.* (Washington, DC: U.S. Gov. Printing Office). p. 75

Closed-Loop Drilling Case Studies

CASE 1: Prima Energy's Cost-Benefit Analysis[39]

Prima Energy Corp. has drilled more than 68 wells in Colorado[40] using a highly automated closed-loop system, which the company started developing along with Nabors Drilling USA, Inc. in 1993. The company found that the economics of drilling these wells in Colorado were best if drilling required less than 12 days. The following table outlines the cost benefit of closed-loop drilling systems.

	Conventional rotary drilling with reserve pit		**Closed-loop drilling with mud motors and diamond bits (50 wells)**	
	Amount	Cost	Amount	Cost
Water	6,400 barrels	$ 4,720	1,200 barrels	$ 1,350
Location	300 x 300 feet	$ 3,000	200 x 150 feet	$ 900
Mud		$ 2,000		$ 1,700
Surface Damages		$ 3,500		$ 2,500
Berm		$ 1,000		0
Mud Haul		$ 2,800		$ 900
Dewatering Unit *		0		$ 8,250
Total		**$17,020**		**$15,600**

* Dewatering cost includes rental of unit, labor, extra fuel, polymer and acid, linear motion shaker, centrifuge, trucking, end loader and miscellaneous costs.

Prima Energy's Calculated benefits of closed-loop drilling:

- cost savings of $1,320 per well
- water savings of 5,200 barrels (closed-loop drilling used 80% less water)

CASE 2: Comparing closed loop drilling to a conventional system: A tale of two wells[41]

Closed-loop systems employ a suite of solids control equipment to minimize drilling fluid dilution and provide the economic handling of the drilling wastes. For one company, a typical closed-loop system includes a series of linear-motion shakers, mud cleaners and centrifuges followed by a dewatering system. The combination of equipment typically results in a "dry" location where a reserve pit is not required, used fluids are recycled, and solid wastes can be landfarmed, hauled off or injected downhole.

Two wells, drilled only 200 ft apart in Matagorda County, TX, provided a unique opportunity to compare the cost savings difference between conventional solids-control equipment and the company's closed-loop system. Both wells drilled through the same formations, using the same rig crew, mud company and bit program.

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[39] Longwell, John and Hertzler, Glenn. (Prima Energy Corp. and Nabors Drilling USA, Inc., respectively). 1997. "Closed-loop system as a cost effective alternative to reserve pits," presented at the *Advances in Drilling Technologies for the North American Rockies Conference* (April 28, 1997, Denver, CO)

[40] Interstate Oil and Gas Conservation Commission. 1999 Chairman's Stewardship Award report. www.iogcc.state.ok.us

[41] www.miswaco.com/More_Info/About_Us/98131.pdf

The closed loop system with improved solids control resulted in some significant savings:

- 43% savings in drilling fluid costs
- 23% fewer rotating hours
- 33$ fewer days to drill to a comparable depth
- 37% reduction in the number of bits used
- up to 39% improvement in the rate of penetration

CASE 3: Reducing waste volume and costs using closed-loop systems[42]

Challenge— Challenges associated with conventional reserve pits include volume of drilling wastes; drill site installation and restoration costs; pollution of land and/or surface water due to failure of pits and/or containment system and associated cleanup costs; and potential for subsurface pollution due to downward migration from pits and/or surface soil permeability.

Solution— Use closed-drilling pit system to reduce volume of drilling waste. The drilling contractor maintained "safe pit levels" and recycled drilling fluid to minimize pit volumes and disposal requirements. Waste management costs due to procedures other than those specified were also the responsibility of the drilling contractor. Cost savings provided the incentive to implement and maintain proper procedures to minimize waste generation in the closed-loop system.

	Conventional reserve pit	**Closed-loop drilling fluid system**
Surface disturbance	reserve pit (235' x 77' x 5') cuttings pit (20' x 10' x 5') water pit (40' x 10' x 5')	No reserve pit necessary.
Total drilling mud and wastes in pits	16,625 barrels	1,100 barrels
	Total reduction in drilling mud and wastes in pits using closed-loop drilling	**15,625 barrels**

Benefits— The following benefits were realized:

1. Total estimated cost savings (considering reduced costs for drill site installation, fluid hauling and disposal, dirt work, and surface damage payment): $11,000.00
2. Reduced surface disturbance by 18,000 square feet (0.4 acres).
3. Reduced drilling mud and wastes in pits by 15,625 barrels.
4. Reduced potential for environmental impact to surface and groundwater.

CASE 4: Closed Loop Drilling Fluid System[43]

Problem— A small independent operator was concerned about the volume of drilling waste in conventional reserve pits at his drilling locations. Waste management costs were a concern, as well as the costs associated with impact on adjacent land due to pit failures. The operator was concerned about the potential for surface water or ground water contamination and the associated potential liabilities.

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[42] New Mexico Oil Conservation Division. *Pollution Prevention Best Management Practices for the New Mexico Oil and Gas Industry*. http://www.emnrd.state.nm.us/ocd/

[43] Railroad Commission of Texas. *Waste Minimization - Case Histories - Drilling Operations.* http://www.rrc.state.tx.us/divisions/og/key-programs/ogkwchdo.html

Solution— The operator was drilling relatively shallow wells in normally pressured strata. Because the drilling plan was relatively simple, the operator investigated the feasibility of using a closed-loop drilling fluid system for these wells. The use of a closed-loop system eliminated the need for a conventional reserve pit. The operator negotiated with drilling contractors to obtain a turn-key contract that required the drilling company to use a closed-loop system and take responsibility for recycling the waste drilling fluid.

Benefits— The turn-key contract was incrementally more expensive. However, because of reduced drill site construction and closure costs; reduced waste management costs; and reduced surface damage payments, the operator realized a savings of about $10,000 per well. Also, the operator reduced the potential for environmental impact and associated potential liability concerns.

CASE 5: Closed-loop system helps reduce drilling waste[44]

A large oil and gas production company used a number of pollution prevention techniques, including closed loop drilling, to drill an exploratory well adjacent to the Tishomingo Wildlife Refuge in Johnston County, OK. The well was drilled on land owned by the U.S. Army Corps of Engineers. Some of the measures taken in drilling the well included:

- Using a closed-loop mud system that allowed for reuse of drilling fluids and use of smaller quantities of water for dilution of the mud to control viscosity and density
- Use of compressed air as the drilling fluid where possible, which allowed for the use of smaller quantities of water and drilling fluid
- Using a smaller casing, which allowed for the use of a 25% smaller hole. This generated a smaller volume of drill cuttings and required less drilling fluid

Savings and Benefits— The hole-size reduction, use of air drilling and closed-loop system reduced wastes by close to 1.5 million pounds. A material and disposal cost savings of $12,700 was achieved.

3. Case Study: The Pit Situation in New Mexico

Numerous types of pits may be constructed to contain liquid and solid wastes created during oil and gas exploration and production. Generally, the pits are shallow, uncovered, and may or may not be lined. Typically, when pits are no longer needed, the fluids are allowed to evaporate, and the leftover sludge is bulldozed over or backfilled. If there is a liner, it is common practice in New Mexico to rip the liner, allow the fluids to seep into the soil, remove the liner (or leave it in place) and then bulldoze over the site.

3.1 Regulation of New Mexico oil and gas pits

In December 2003, the New Mexico Oil Conservation Commission passed a rule regulating pits and below-grade tanks that are associated with oil and gas development. This rule required that an inventory of oil and gas pits occur by establishing a “pit permit” system; and the rule fine-tuned the state’s regulation of pit construction, operational standards, and reclamation. For a number of reaons, the 2003 rule is inadequate:

[44] Oklahoma Department of Environmental Quality. *Pollution Prevention Case Studies.* http://www.deq.state.ok.us/CSDnew/P2/Casestudy/oxyusa%7E1.htm

- does not require closed systems for drilling fluids and cuttings to protect fresh water supplies and soil contamination;
- while generally "prohibiting unlined pits," it allows for exemptions from this "prohibition" in the eight major oil and gas producing counties;
- it allows for on-site disposal of drill fluids, chemicals and salts;
- it fails to require the OCD to characterize and record pit waste; and
- it widely enables the OCD to grant routine and broad exemptions to the rule.

3.2 Contamination from New Mexico pits

How many pits are there?

As mentioned above, in December of 2003, the New Mexico Oil and Conservation Division (OCD) began requiring companies to receive permits for pits. Up until that time permits for pits were not required, so the OCD did not have reliable records of how many pits existed in the state. Consequently, at the present time the best data available on the number of pits in the state comes from a request made by the OCD to oil and gas operators in 1997, asking for information on lined and unlined pits.

Based upon the responses received by the OCD (only 251 operators responded, out of more than 750 operators in the state[45]), there are at least 13,200 pits in New Mexico – 5,600 lined and 7,600 unlined.[46]

With only one-third of operators responding, it is highly likely that there are significantly more than 13,200 pits in the state. Using rough calculations based on the number of wells in the state, it is likely that there are tens of thousands of pits located throughout the state.

- As of October, 2003, there were 39,874 producing wells in New Mexico.[47]
- If every one of these operations used just one pit, there would be close to 40,000 pits in the state.
- It is probable that most operations use more than one pit. Oil and gas operations may use numerous pits during the drilling stage, well completion stage, production stage, as well as emergency pits to contain spills. So the number of pits in the state may well exceed 40,000.

What wastes are going into oil and gas pits in New Mexico?

- In 1999, it was estimated by the New Mexico Oil Conservation Division (OCD) that more than 90% of all drilling muds and cuttings were disposed of in pits. The volume of drilling wastes

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[45] New Mexico Energy, Minerals and Natural Resources Department. *Factsheet: Well Operators in New Mexico* (http://www.emnrd.state.nm.us/ocd/)

[46] Letter from Roger C. Anderson, Environmental Bureau Chief, New Mexico Energy, Minerals and Natural Resources Department, to Jennifer Goldman, OGAP. Oct. 23, 2003.

[47] New Mexico Energy, Minerals and Natural Resources Department *Factsheet: New Mexico Well Statistics* (http://www.emnrd.state.nm.us/ocd/)

disposed of in pits was approximately 89,000 yd^3 (almost 18 million gallons) of drill cuttings and 1,134,400 barrels (about 47 million gallons) of drilling fluids.[48]

- OCD also estimates that about half of all "associated wastes" are disposed in pits. No estimates are available for volume of associated wastes produced in New Mexico.[49] Associated wastes are exploration and production wastes other than produced water and drilling muds and cuttings. These wastes would include: hydraulic fracturing fluids; and wastes from field processing facilities such as glycol dehydrators and separators.

- About 59 million barrels (about 2.5 billion gallons) of produced water were disposed in on-site pits and in commercial and centralized surface impoundments in New Mexico.[50]

Pit Contamination in New Mexico

The Oil Conservation Division (OCD) does not know how many of the 13,200 documented pits are currently causing contamination of soil or groundwater.

Between the mid 1980s and 2003, however, the New Mexico Environmental Bureau recorded more than 6,700 cases of pits causing soil and water contamination, with at least 557 of those cases resulting in groundwater contamination. More than 360 of those 557 groundwater contamination sites investigated by the New Mexico Environmental Bureau are not yet fully cleaned up.[51]

Since 2001, the OCD has investigated 734 cases of soil or groundwater contamination; 444 of the investigations were conducted at field production locations (e.g., well sites as opposed to major processing facilities).[52]

Examples of Contamination:

Duncan Oil Field[53]

Contamination of groundwater and nearby soils with hydrocarbons from an unlined pit was documented in the Duncan Oil Field west of Farmington, New Mexico. Waste pits containing produced water were found to contain large amounts of polycyclic aromatic hydrocarbons, which are phototoxic to fish, and may cause cancer, organ damage and reproductive effects in humans. Volatile hydrocarbons including benzene (a carcinogen),

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[48] New Mexico Energy, Minerals and Natural Resources Department, Oil Conservation Division.. August, 2001. *State Review of Oil and Natural Gas Environmental Regulations, Inc. Follow-up and Supplemental Review.* (www.strongerinc.org/pdf/NMfinal.pdf)

[49] New Mexico Energy, Minerals and Natural Resources Department, Oil Conservation Division.. August, 2001. *State Review of Oil and Natural Gas Environmental Regulations, Inc. Follow-up and Supplemental Review.*

[50] New Mexico Energy, Minerals and Natural Resources Department, Oil Conservation Division.. August, 2001. *State Review of Oil and Natural Gas Environmental Regulations, Inc. Follow-up and Supplemental Review.* www.strongerinc.org/pdf/NMfinal.pdf

[51] Letter from Roger C. Anderson, Environmental Bureau Chief, New Mexico Energy, Minerals and Natural Resrouces Department, to Jennifer Goldman, OGAP. Oct. 23, 2003.

2001. *State Review of Oil and Natural Gas Environmental Regulations, Inc. Follow-up and Supplemental Review.* www.strongerinc.org/pdf/NMfinal.pdf

[53] Eiceman, Gary Alan. 1986. *Hazardous Organic Wastes from Natural Gas Production, Processing And Distribution: Environmental Fates.* New Mexico Water Resources Research Institute. http://wrri.nmsu.edu/publish/techrpt/abstracts/abs227.html

toluene, and xylenes were found in water, and polycyclic aromatic hydrocarbons were found in the soil downgradient from earthen pit at distances up to 164 feet away.

Hampton Well (Natural Gas) Site[54]

For more than 12 years the Public Service Company of New Mexico (PNM) discharged liquids removed from natural gas (using dehydration equipment) into an unlined disposal pit, located at the northern-most portion of the Hampton Well Site in San Juan County, New Mexico. The dehydration liquids included liquid hydrocarbons. In 1996, PNM discovered potential hydrocarbon contamination from the pit and began closing the site. In January, 1997, PNM notified the New Mexico Oil Conservation Division's Environmental Bureau that groundwater beneath the former pit was indeed contaminated by hydrocarbons.

Also in 1997, Burlington Resources Oil and Gas Company (Burlington), which was operating well equipment located in the southern-most portion of the Hampton Well site, discovered a hydrocarbon seep along the northwestern edge of their well site. This seep was also coming from a former pit.

As of November, 1998, neither PNM nor Burlington had completed remediation activities at the Hampton Well site. Groundwater contamination was still a problem, and a plume of contamination extended approximately 1000 feet downgradient from the site. As of 2000, according to the New Mexico Oil Conservation Commission, contamination at the Hampton Well site remained a threat to public health and safety and the environment.

Banning Pits to Protect Water Supplies

In an effort to protect municipal water supplies, the city of Lovington, NM recently passed an ordinance that prohibits companies that operate on the city's water-field from permanently disposing of drilling wastes in pits on site. See Appendix II for news articles on this issue.

[54] State of New Mexico Energy, Minerals And Natural Resources Department Oil Conservation Commission. March 24, 2000. Hearing Called By The Oil Conservation Commission For The Purpose Of Considering: Application Of Public Service Company Of New Mexico For Review Of Oil Conservation Division Directive Dated March 13, 1998, Directing Applicant To Perform Additional Remediation For Hydrocarbon Contamination, San Juan County, New Mexico. Case No. 12033 Order No. R-11134-A http://www.emnrd.state.nm.us/ocd/Orders/Hearing/2000/12033-A.pdf

Appendix I

Web links to closed-loop drilling service companies

There are many companies that provide closed-loop drilling services. While OGAP does not endorse any of these companies, we are providing some links so that readers can do more research on these systems.

These companies all claim to use closed-loop drilling fluid or “zero discharge” drilling systems. Zero discharge means different things to different companies. For some, it means zero discharge of fluids, while others stress the zero discharge of wastes into earthen pits. Be sure to read the fine print, and contact the companies to discuss what they can and can’t accomplish with their systems.

* Brandt (a Varco Company) http://www.brandtvarco.com/
* M-I-SWACO http://www.miswaco.com/
* Soli-Con http://www.soliconequipment.com/
* Kem-Tron http://www.kemtron.com/
* Tri-Flo International Inc. http://www.triflo.com/
* Fluid Systems Inc. http://www.fluidsystems.us/
* Flottweg http://www.flottweg.com/index_en.html
* Lakefront Enterprises, Inc. http://www.enviro-bond.com/

Appendix II

Press Clips

The Lovington Daily **LEADER**

City Worries About Safety Of Its Water Supply

By GINGER GRANATH
Tuesday, September 16, 2003

City employees brought in 20 more chairs to an already packed house to accommodate the huge crowd at the city commission meeting last night. Over 50 oil and gas producers, service company owners, lawyers and bureaucrats packed the commission chambers at City Hall, the majority in protest to Ordinance 449 -- the city's proposed ordinance to require more stringent compliance for oil and gas activity in the city's water field, five miles south of Lovington.

The City of Lovington draws 100 percent of its water from 17 wells on approximately 1,900 acres south of town -- and allows rights-of-way in the field to 22 different oil and gas companies.

But there are problems out there, says City Manager Pat Wise, and while the city's drinking water has not been contaminated yet, it very easily could be.

"It is my thought that we must do everything we can to protect our municipal water supply," Wise told the audience and commissioners. "That's the lifeline of this community, and if we lose it, we lose the community."

In his 18 months as city manager, Wise explained that he has seen several problems in the water field. "On the east side [of the water field], there were four oil pipeline leaks. None were reported, three were one company.

On the west side, there was the rupture of a pipeline that knocked down two city employees, four more pipeline leaks, and none were reported to us, we did find them ourselves. On one, we found a pipeline worker attempting to remediate the site before they notified the city -- it's still leaking as we speak."

Wise said because several calls to the companies that own the facilities, and the state OCD (Oil Conservation District), the state's regulatory agency, have been unfruitful, he asked the city's legal counsel to draw up an ordinance which requires all spills to be reported to the city, and gives the city more power to regulate the oil and gas activity on the 1,900 acre water field. In effect, the 18-page ordinance gives power to the city that would otherwise be in the hands of the OCD -- and that is what drew the crowd of concerned oil and gas producers and others.

Mike Feldewert of the New Mexico Oil and Gas Association spoke on behalf of the membership: "We're not here in opposition to your goals and objections," he told the commissioners, "what we're disputing here today is the means the city has set forth to accomplish these goals. We would suggest this ordinance is not necessary."

While it wasn't stated, Feldewert and others who took a turn at the podium to voice their opposition, implied that the commission would be inviting litigation if it passed the ordinance. "Let's face it, we all live in a legalistic world now," said David Purdy of Devon Energy. "If you would be willing to focus your power as a governing body to the people in the state agencies who have the responsibility, and don't back off, you'll do everybody a favor, and in the end solve the problem you have here."

Further, Purdy argued, the city shouldn't punish the prudent operators for the actions of a few non-compliant oil companies. "For a company that has opted to not follow the rules, 25 more rules will not get the bad apple out of the cart."

The oil and gas producers seemed concerned that if Lovington could pass such a strict ordinance, establishing another layer of permits and reporting, then other municipalities could follow suit, and soon there would be too many layers of red tape for operators to do business.

"If [the ordinance] moves forward, this is a serious issue for the industry.
We're going to have a municipal layer, state layer, federal layer; that creates confusion," said Feldewert. "It's unnecessary and in the end we really don't know whose in charge ... and there may be some problems there as far as enforcement."

Currently, the oil and gas industry is required to report leaks, spills and other problems to the OCD. But Wise's complaint is that the OCD is completely ineffective in enforcing the state statutes. "If we rely on the
layers of bureaucracy that are in place, there's been one problem out there ... since 1992. That's how responsive the OCD has been to the city," complained Wise.

"I'd just ask that consider what you're doing," said Harry Teague, county commissioner and owner of Eunice Well Service. "You can see how that becomes burdensome for the companies. There is going to be a lot of money spent, but it’s not going to be spent clarifying the water problem. Think real strongly about it before you give up on OCD, your elected officials, your state representatives, your state senators, your governor. I'd ask you to spend some money that way before you start spending money on litigation. When we start doing these things we're going to have an effect on a lot of people's way of life."

The city commissioners listened intently to six different speakers, and then decided to hold off on passing the ordinance until they could gather more input from the oil and gas industry. "I'm kind of like some of those [speakers]," said Mayor Pro-Tem Bill Shipp after the presentations were made and the room cleared out. "Where do you stop adding regulations on regulations. ... I know there's a middle of the road here, let's don't hastily do something. This is a good start, we've got their interest."

"I am a little bit leery of just throwing this [ordinance] out there and making it more difficult for some oil companies that are doing what they're supposed to do," agreed Commissioner Dixie Drummond, who then asked if the non-compliant companies' rights-of-way could be revoked.

Patrick McMahon, the city's legal counsel, said that he and Wise were researching the rights-of-way, and that some of the documents are "pretty old." "We're not sure all the companies out there have the proper right-of-way to have property out there," said Wise.

The names of the companies dragging their feet on reporting and cleanup in the city's water field (five companies responsible for seven recent incidents) weren't disclosed at the commission meeting, but Wise said "none of those that spoke were the guilty parties."

"It's got their attention," Harris said of the proposed ordinance. "I agree, we don't need another layer of regulations, ... we need to put pressure on them."

Wise got the permission of the commission to address another letter to the OCD and see if some of the problems with the non-compliant companies in the water field would be addressed. In the meantime, the commissioners requested more input from the oil and gas industry, with the hopes that if an ordinance was required, it would be satisfactory for all involved parties. ■

HOBBS News-Sun

Lovington City Commission Meets

By: Michelle A. Fox

October, 28, 2003

The problem of oil companies contaminating soil and other resources in Lovington took center stage Monday night, but found that the city's concerns were not a problem unless officials with the state were apprised of it.

The Lovington City Commission had invited Chris Williams of the Oil Conservation Division of the New Mexico Energy, Minerals and Natural Resources Department to Monday's meeting to address the problem of soil reclamation due to oil and gas-related contamination occurring in the city's 1,800-acre water field.

"I do not know what the solution is," said Williams. "We have two environmental agents for three counties. We do not know about a problem unless someone tells us about it."

City manager Pat Wise talked of an oil company that spilled 1,800 barrels of oil, failed to notify anyone and simply covered the spill with dirt.

"There is drinking water 50 feet under that spill," Wise said. "That scares the hell out of me. I have had oil companies tell me they do not think about the environmental concerns."

Citing notification as a main problem and the cost of removing equipment left by defunct companies as another, Williams talked about budget issues.

"We have talked about raising the reclamation fund, but we are afraid if it gets too high it will become a target for spending other than reclamation," Williams said.

According to Williams, it is costing the state $101,000 to take soil samples from Lovington's Araho site -- which has 4 feet of oil and sludge sitting in a pit there since 1992.

After it is decided how far down the site will need to be excavated, it could cost up to another $50,000 to finish the project. It is unknown how far down the contamination goes.

The pit at the site could cost $120,000 to clean up.

Lovington mayor Troy Harris was not moved by the personnel and budget issues of the division.

"We have a water field we need to protect," Harris said. "Through the years, your agency has not done its job. We have reported problems and they have not been addressed. If they have been, it was months or years later."

Harris told Williams that if the division was not going to take care of the problems, the city would do what it could to take care of them.

Representatives from the OCD along with Bob Gallagher of the New Mexico Oil and Gas Association will be in Lovington on Nov. 7 for a tour of the water field.

In other business the commission:

* Accepted the resignation of members of the entire Lodgers' Tax Board.
* Approved variance zoning to Randall and Joyce Gandy.
* Awarded the bid for the 17th Street Project to Armstrong Construction.
* Awarded the bid for engineering on the Senior Center Therapy Pool to The Larkin Group of Albuquerque.
* Accepted the city manager recommendations for board appointments. ■

The Lovington Daily **LEADER**

State Officials Get Close Look at Contamination Threat

By: Ginger Granath
November 11, 2003

It seems City Manager Pat Wise may having finally gotten the attention of the New Mexico Oil Conservation District (OCD). Friday, Wise arranged a bus tour into the city's 1,800 acre water field south of town to show everyone the oil spills plaguing the land. Four OCD representatives attended, including Director Lori Wrotenbery.

Bob Gallagher, director of New Mexico Oil and Gas Association; Steve Daly with the Bureau of Land Management; Mayor Troy Harris; Mayor Pro-Tem Bill Shipp; Charles Kelley, assistant city manager; Patrick McMahon and Mike Newell, the city's legal counsel; and Jennifer Goldman of the New Mexico Oil and Gas Accountability Project rounded out the group.

Loaded up in a yellow school bus, Wise showed the group five problem areas and pointed out the city's 17 water wells.

At each stop, Wayne Price, Gary Wink, and Bill Olson of OCD walked each site, listed the irresponsible operators, and made field notes.

"Yeah, it's pretty obvious there's something that's there because of the hydrocarbon smell," said Price after examining blackened soil near a poorly repaired pipeline. It appeared someone tried to cover the spill with sand; it wasn't immediately clear to the OCD staff or city officials who the responsible party was for the spill.

The dark soil encompassed a large area that was just up stream from one of the city's water wells. "The gradient is headed right toward that municipal well," Wise said pointing to the well just southeast of the spill.

What isn't known is whether or not any of these surface problems have reached the fresh water aquifer 50 to 55 below the surface. The City of Lovington draws 100 percent of its water from 17 wells on 1,800 acres south of town -- and allows rights-of-way in the field to 22 different oil and gas companies. Water in the well field is not currently contaminated, but in the past one of the city's wells was shut-in after contamination was found.

"What you have is leak upon leak upon leak upon leak," said McMahon pointing to a hardpan area where black soil snaked around two leaky tank batteries, "and what should happen is they should come out here and drill down to the ground water and see how far this stuff goes. It's possible it goes ten feet down and stops, but in their experience I bet they're going to tell you there's a good probability the ground water is going to be impacted."

"Until we check into it further, we really can't comment on the seriousness of it," said Wrotenbery after viewing the first two sites. "What we do plan to do is take a look at this whole area and put together a report for the city on what we find, document what has happened in the past, and what work has been done."

One site, the Araho site, was abandoned over 11 years ago with tank batteries and a lined pit full of black sludge left behind. At Wise's persistence, the OCD has begun cleaning up that site, removing the corroded tanks. The pit is still there, and Olson said his staff has drilled monitor wells around it. "Monitor wells were drilled, bore wells were drilled and this liner so far is intact and is holding," he explained to the group, "and we do have good clean water under this pit, so we're real fortunate of that." According to Wise, the surety bond on the site was released from the state back to the oil company years ago, leaving the cleanup cost, which will run hundreds-of-thousands of dollars, in the hands of the OCD.

The first step when a person sees an apparent leak is to notify the operator, who is supposed to have the company name and contact number clearly marked. A person can

also contact OCD to report the leak. Olson explained the district's role: "The first thing we do is try to find a responsible party" when there is a problem. "It's their responsibility for environmental cleanups, unless the site is truly abandoned." In those instances, OCD often has to foot the bill: "We try to work with monies we have to clean up sites."

It's not always that easy, though, said Olson pointing to an apparently abandoned facility with a Penrock sign in front. "Penrock is still a viable company, the sign says Penrock, [but] sometimes they're sold and the signs aren't changed."

This past year, when numerous calls to operators and the OCD failed to produce results, Wise became worried. He asked the city's legal counsel to draft ordinance 449, a city ordinance which would regulate oil and gas operations in the city's 1,800 acre water field. There is a New Mexico state statute that allows a city to pass ordinances to protect its municipal water, which is the legal portal for the city's ordinance.

Prior to introducing the ordinance at the September 15 city commission meeting, several representatives of the oil and gas industry got wind of it, and showed up en masse to voice strong opposition. Some industry representatives suggested that by passing the ordinance, the city would subject itself to costly litigation. Since then, two organizations, the New Mexico Cattle Growers Association and the Oil and Gas Accountability Project, along with several farmers and ranchers have publicly supported the ordinance. (The city commission has not adopted the ordinance yet, which is in its second draft.)

"We need a lot better enforcement," said Goldman, who joined Friday's tour from the OGAP's office north of Taos, "although a lot of the problems are the regulations." According to its mission statement, OGAP was created in 1999 to "advocate for greater corporate and governmental accountability, responsibility, and respect for people and places in the course of oil and gas development."

Goldman took a great deal of interest in the apparent damage on the surface of the land, snapping pictures and taking notes, while conversely, Gallagher, the director of NMOGA, the largest organization of New Mexico producers, referred to the tour as a "media circus" and did not leave the bus to view the final three sites.

The tour concluded after about an hour-and-a-half. Wrotenbery and her staff stayed around at City Hall to discuss issues with Wise, McMahon, Harris and Shipp.

Last night, Wise briefed the city commission on the day, saying he was pleased with the progress. "I thought it went wonderfully," he said. "We took them to five different sites, existing batteries, abandoned batteries, pipeline blowouts. ... I think they understand our pain now, I certainly hope so." ■

nature climate change

PERSPECTIVE

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Energy system transformations for limiting end-of-century warming to below 1.5 °C

Joeri Rogelj[1,2]*, Gunnar Luderer[3]*, Robert C. Pietzcker[3], Elmar Kriegler[3], Michiel Schaeffer[4,5], Volker Krey[1] and Keywan Riahi[1,6]

Many impacts projected for a global warming level of 2 °C relative to pre-industrial levels may exceed the coping capacities of particularly vulnerable countries. Therefore, many countries advocate limiting warming to below 1.5 °C. Here we analyse integrated energy–economy–environment scenarios that keep warming to below 1.5 °C by 2100. We find that in such scenarios, energy-system transformations are in many aspects similar to 2 °C-consistent scenarios, but show a faster scale-up of mitigation action in most sectors, leading to observable differences in emission reductions in 2030 and 2050. The move from a 2 °C- to a 1.5 °C-consistent world will be achieved mainly through additional reductions of CO_2. This implies an earlier transition to net zero carbon emissions worldwide, to be achieved between 2045 and 2060. Energy efficiency and stringent early reductions are key to retain a possibility for limiting warming to below 1.5 °C by 2100. The window for achieving this goal is small and rapidly closing.

Avoiding 'dangerous anthropogenic interference with the climate system'[1] is the ultimate objective of international climate negotiations. This objective is explicitly supported by all 195 countries that are represented within the United Nations Framework Convention on Climate Change[1] (UNFCCC). However, climate impacts are not distributed evenly over the globe[2], and local capacities to adapt to or cope with these impacts can differ significantly among regions. This is one reason why, so far, no strong political consensus has been reached about what level of climate change is to be considered 'dangerous'[3], and therefore what unambiguously defined level of global warming should be avoided.

Since the 2010 Cancún Agreements[4], all countries represented within the UNFCCC have recognized that strong emission reductions are required to achieve the long-term global goal of limiting warming to below 2 °C relative to pre-industrial levels. At the same time, a periodical review of the adequacy of this long-term goal with respect to the convention's ultimate objective was decided on, the first of which is currently underway and is to be concluded by the end of 2015. This periodic review needs to be understood from the perspective that more than half of the world's countries represented within the UNFCCC consider that the local impacts projected for a 2 °C world are already beyond what their societies would be able to cope with, in the short or long term. This group of countries, which includes the Alliance of Small Island States[5,6] (AOSIS) and the least-developed countries[6] (LDCs), therefore support and pursue the introduction of a more stringent global temperature limit of 1.5 °C as part of a future agreement. Furthermore, the IPCC's assessment of incremental climate impacts (see ref. 7) has elevated the importance of considering a long-term global goal more stringent than 2 °C.

Options for limiting the global mean temperature increase to below 1.5 °C have therefore become of central interest to the UNFCCC process. Historical temperatures have already increased by a total of 0.78 °C (0.72–0.85 °C, 90% confidence interval)[8] between 1850–1900 and 2003–2012. Furthermore, steadily increasing global carbon emissions[8–10] are committing the world to increasing levels of long-term warming owing to cumulative historical emissions and lock-in of carbon-intensive energy infrastructure. Limiting warming to below 1.5 °C is thus undoubtedly a very challenging task.

We here characterize scenarios consistent with a 1.5 °C temperature limit by 2100 relative to pre-industrial levels and describe their differences with respect to scenarios that limit warming to below 2 °C. We base our study on the integrated assessment modelling literature and look at six different aspects: (1) emissions in the short and long term; (2) the pace of the energy-system transformation; (3) the contribution of different sectors of the energy system; (4) the importance of critical technologies such as carbon capture and storage (CCS); (5) implications for climate policy; and (6) the costs and financial needs in terms of investments.

So far, only a few studies[11–15] have reported scenarios consistent with a 1.5 °C limit, and no study focuses specifically on the energy-system characteristics of 1.5 °C scenarios or includes results from multiple integrated assessment models (IAMs). Here we fill this gap by drawing on a set of more than 200 low stabilization scenarios from the MESSAGE[12,13] and REMIND[11] IAMs. Owing to their representation of a wide variety of emission reduction options, MESSAGE and REMIND are classified as models that are 'highly responsive' to climate policy[16]. They are thus well-suited for analysing very deep decarbonization pathways, which other models may not find feasible. Some other studies were not included here because they do not provide the desired sectorial detail[15] or looked at the 1.5 °C target beyond the twenty-first century[14]. Future temperature change is projected with the MAGICC[17] model in a probabilistic set-up[18,19] (Methods). Despite being a simple carbon cycle

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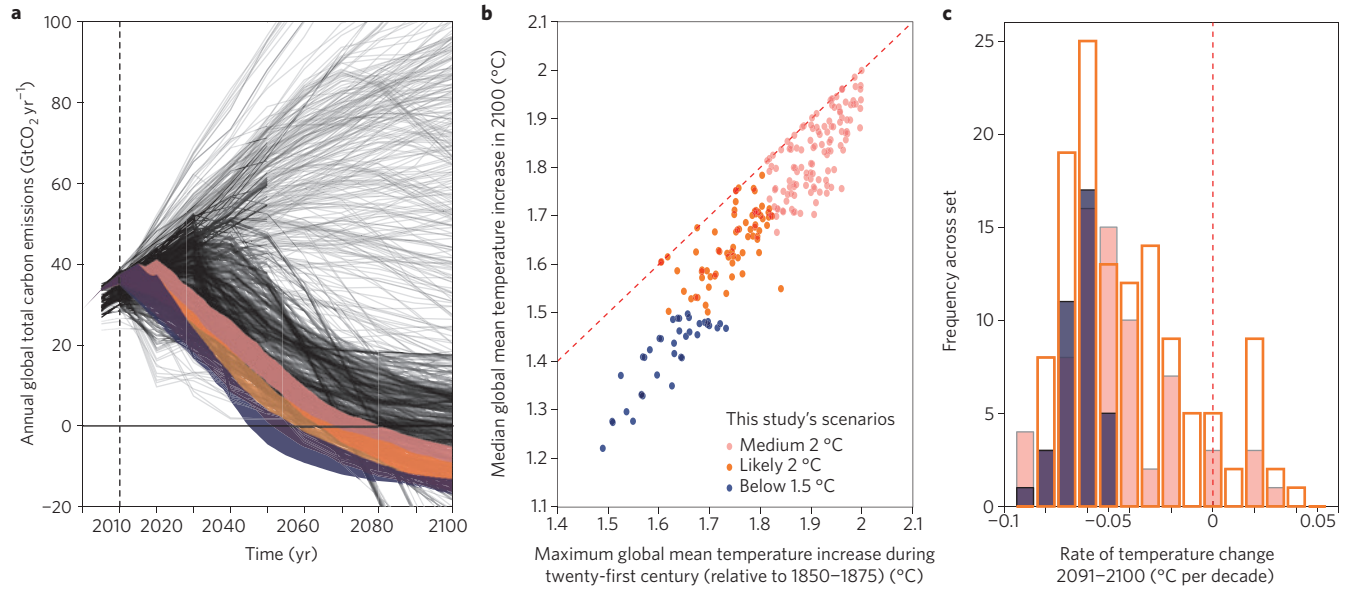


Figure 1 | Emission profiles and temperature outcomes of 1.5 °C-consistent scenarios. a, Total global annual carbon emissions over time. Coloured areas represent the 15th–85th percentile range of the three scenario groups used throughout this paper. Pink: medium 2 °C scenarios—limiting warming during the twenty-first century to below 2 °C with 50–66% chance; orange: likely 2 °C scenarios—limiting warming during the twenty-first century to below 2 °C with >66% chance; blue: 1.5 °C scenarios—limiting warming in 2100 to below 1.5 °C with >50% chance. Thin black lines are scenarios included in the IPCC AR5 scenario database. **b,** Maximum median temperature increase relative to pre-industrial levels during the twenty-first century is shown relative to temperature increase in 2100. Scenarios that reach their maximum temperature increase in the twenty-first century in 2100 lie on the diagonal red dashed line. As the blue dots show, temperature rise in 1.5 °C-consistent scenarios is lower in 2100 than at its maximum point during the twenty-first century. Global mean temperature in these scenarios has thus peaked before and is declining by 2100. This is not necessarily the case for 2 °C-consistent scenarios (pink and orange dots). **c,** Rates of temperature change between 2091 and 2100. Colour coding is consistent across panels. The vertical red dashed line visually delineates scenarios that have stabilized or are decreasing temperatures by the end of the twenty-first century from scenarios that are still warming.

and climate model, global mean temperature changes computed with this set-up of MAGICC closely match the results of complex general circulation models (see refs 18, 20–22). The Supplementary Information compares this study to the IPCC Fifth Assessment Report (AR5).

The 1.5 °C target

Climate targets can be expressed in a variety of ways. However, there are uncertainties associated with how the Earth system responds to anthropogenic forcing. Therefore, temperature targets are commonly expressed in terms of a specific temperature limit and a minimum probability of observing that limit[23–25]. These probabilities can be assessed at any point in time. Most 2 °C studies have focused on scenarios that do not fall below a certain probability during the entire century[19,24,25]. However, no scenarios that have a high probability of limiting warming to below the 1.5 °C limit during the entire twenty-first century exist in the literature. Typically, 1.5 °C scenarios temporarily have lower probabilities of staying below 1.5 °C during a certain period of the twenty-first century than in 2100. This is referred to as a temperature 'overshoot'.

Here we group the scenarios according to the end-of-century probability for limiting warming to below 1.5 °C and, in addition, explore the likelihoods of not exceeding 2 °C at any point in time. In summary, we distinguish three categories that broadly reflect the most prominent temperature objectives discussed in policy circles[24].

1.5 °C scenarios (or 1.5 °C-consistent scenarios). Scenarios that return warming to below 1.5 °C relative to pre-industrial levels by 2100 with greater than 50% chance. All these scenarios also have a likely[26] (>66%) chance of keeping global warming below 2 °C in the twenty-first century.

Likely 2 °C scenarios. Scenarios that have a likely[26] (>66%) chance of keeping maximum global warming in the twenty-first century below 2 °C relative to pre-industrial levels, but have a less than 50% chance of not returning warming to below 1.5 °C by 2100.

Medium 2 °C scenarios. Scenarios that have a medium (50–66%) chance[24] of keeping maximum global warming in the twenty-first century below 2 °C relative to pre-industrial levels, and have yet a lower chance of limiting warming to below 1.5 °C by 2100.

Using the labels defined above, 1.5 °C scenarios are the focus here. We assess their difference with respect to likely and medium 2 °C scenarios. At times, the combination of likely 2 °C scenarios and medium 2 °C scenarios is referred to as '2 °C scenarios' in short, if findings apply to both sets of scenarios.

Emissions and temperatures

Global emissions in our selection of 1.5 °C scenarios are at and below the lower bound of emission scenarios available in the IPCC AR5 scenario database, both in terms of CO_2 and total greenhouse-gas (GHG) emissions (Fig. 1a; Supplementary Fig. 1). This results in global mean warming being limited to less than 1.5 °C by 2100, although median temperature estimates are higher over the course of the century (Fig. 1b). Recent experiments with state-of-the-art atmosphere–ocean general circulation models (AOGCMs; see refs 27, 28) in principle support the possibility that global mean temperature rise can be reversed in very low GHG emission pathways[29] in which CO_2 is actively removed from the atmosphere. Although most of the 2 °C scenarios (from both the likely 2 °C scenarios and the medium 2 °C scenarios) also show such a peak and decline behaviour in temperatures, several occurrences can be found of 2 °C scenarios that only stabilize temperatures by 2100, or have still slightly increasing temperatures afterwards (Fig. 1b, pink and

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orange symbols). In contrast, all the 1.5 °C scenarios show a peak and decline of temperature. By the end of the century (2091–2100) global mean temperatures are declining again by at least about 0.05 °C per decade (Fig. 1c).

The lower 2100 temperatures of 1.5 °C scenarios are driven by lower CO_2-equivalent (CO_2e) concentrations by the end of the century. The 1.5 °C scenarios assessed here have a range of 420–440 parts per million (ppm) CO_2e in 2100, while likely and medium 2 °C scenarios show ranges of 455–480 and 480–515 ppm CO_2e, respectively (all ranges in this paper refer to the 15th–85th percentile range unless explicitly indicated otherwise). For comparison, the lowest scenario category of the IPCC Working Group III contribution to AR5 has 430–480 ppm CO_2e in 2100. In contrast to temperatures, CO_2e concentrations peak and decline in virtually all 1.5 °C and 2 °C scenarios in our set (except for a few medium 2 °C scenarios).

Maximum global mean warming is proportional to the cumulative amount of long-lived GHG emissions (particularly CO_2) until the peak of warming[8,19,30–34]. Although radiation-modifying species other than CO_2 contribute to anthropogenic climate change, CO_2-induced warming is the dominant factor[35]. In 1.5 °C scenarios, a long-term peak and decline of temperatures is associated with cumulative carbon emissions having peaked during the twenty-first century. At some point, CO_2 is thus overall being (net) removed from—instead of emitted into—the atmosphere by the activities of the global energy and land-use system. How these scenarios achieve such CO_2 removal is discussed in more detail below.

Limiting end-of-century warming to 1.5 °C relative to pre-industrial levels leaves a very tight budget for remaining carbon emissions[36], which indiscriminately implies achieving net negative CO_2 emissions after 2050. Looking at IAM scenario data from the literature, we find that all 1.5 °C scenarios have lower cumulative carbon emissions over the 2011–2100 period than over the 2011–2050 period (Fig. 2). For instance, the range of cumulative carbon emissions in 1.5 °C scenarios is 680–895 $GtCO_2$ from 2011 to 2050, and 200–415 $GtCO_2$ from 2011 to 2100 (to the nearest 5 Gt). This illustrates the active net removal of large amounts of CO_2 from the atmosphere during the second half of this century in these scenarios (that is, about 375–605 Gt). For comparison, the IPCC Working Group III contribution to AR5[37] reported cumulative carbon emission ranges for 1.5 °C-consistent scenarios of 680–800 $GtCO_2$ and 90–310 $GtCO_2$ for the periods 2011–2050 and 2011–2100, respectively (10th–90th percentile ranges; see Supplementary Information). For the lowest scenario category that was part of the IPCC's scenario assessment (and that has a likely chance of limiting warming to below 2 °C), the IPCC provides ranges of 550–1,300 $GtCO_2$ and 630–1,180 $GtCO_2$ for the two respective periods[37].

Despite having higher cumulative emissions than 1.5 °C scenarios (Supplementary Tables 1–3), the 2 °C scenarios assessed here still include large amounts of net negative cumulative carbon emissions over the twenty-first century (in the range of −350 to −125 $GtCO_2$ and −315 to −60 $GtCO_2$ for likely and medium 2 °C scenarios, respectively). Virtually all scenarios in our set thus achieve net zero carbon emissions globally (that is, carbon neutrality) before the end of the century. Our 1.5 °C scenarios achieve this by mid-century (between 2045 and 2060; Fig. 1a), about 10–20 yr earlier than likely 2 °C scenarios. This accelerated phase-out of CO_2 emissions translates by 2030 to a much lower and substantially smaller range of emissions consistent with limiting warming to below 1.5 °C by 2100, compared with limiting warming to 2 °C (Fig. 1a; Supplementary Tables 1–3).

An increase in atmospheric GHG concentrations results in a perturbation of the Earth's energy balance, which is called radiative forcing. This forcing is kept to low levels by 2100 in 1.5 °C scenarios (circa 2.2–2.4 W m^{-2} relative to 1750). Despite strongly net negative CO_2 emissions in the second half of the century, CO_2 forcing still contributes about 70% of total anthropogenic radiative forcing by 2100 in 1.5 °C scenarios, compared with about 75% in 2 °C scenarios, both today[35] and in 2100. However, with CO_2 being actively removed from the atmosphere, residual non-CO_2 forcing will play an increasingly important role and can influence the remaining space for CO_2 emissions during this century in low stabilization scenarios.

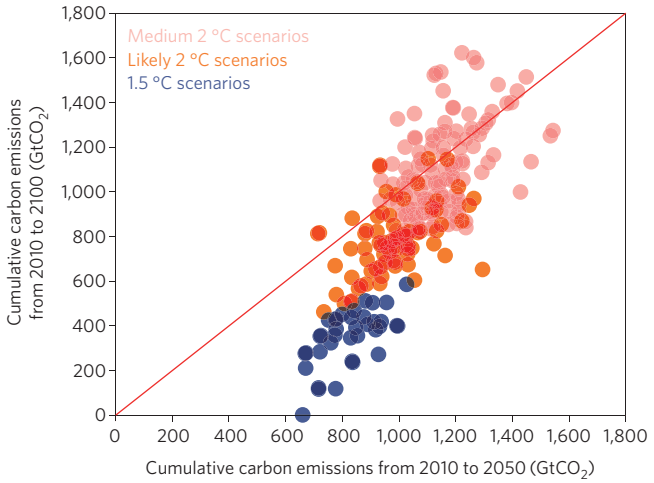


Figure 2 | Cumulative carbon emissions by 2050 and 2100. The cumulative amount of total global carbon emissions between 2010 and 2050 (horizontal axis), and 2010 and 2100 (vertical axis) is given, for three scenario sets, respectively. Note that for most likely 2 °C scenarios and for all 1.5 °C scenarios the cumulative carbon emissions between 2010 and 2100 are lower than between 2010 and 2050. This indicates that CO_2 is actively removed from the atmosphere in the second half of the twenty-first century, by BECCS for example. This is not the case for the medium 2 °C scenarios (pink).

In the scenarios assessed here, almost all of the additional emissions reductions that are required to move from a 2 °C to a 1.5 °C scenario are achieved by reducing CO_2 emissions from fossil fuel use, and by using CO_2 removal via bioenergy combined with CCS (BECCS) and management of land-use sinks. Additional emissions reductions from non-CO_2 gases are very small, as almost their entire assumed abatement potential is already exhausted in the 2 °C scenarios assessed here (Supplementary Fig. 3). Although the 1.5 °C-consistent scenarios presented here currently represent the most ambitious end of CO_2 mitigation, they are not at the extreme end in terms of other GHGs (Supplementary Fig. 2). Both for methane (CH_4) and nitrous oxide (N_2O), significantly lower emission scenarios are available in the literature. This high residual share of non-CO_2 gases by 2100 is largely due to the relatively low abatement potential of CH_4 and N_2O emissions from agriculture that is implemented in the analysed IAMs (but that is in line with the existing literature on low stabilization scenarios[38,39]). If mitigation technologies for non-CO_2 GHG emissions from agriculture advance further than currently expected, or demand for emission-intensive food products increases less than expected, the probability of limiting warming to low levels can be further increased.

Transformation and decarbonization

Having looked at emissions characteristics of 1.5 °C scenarios, the question arises of through which transformations this could be achieved.

We therefore turn to the energy system, and explore the underlying drivers for this transformation during the twenty-first century.

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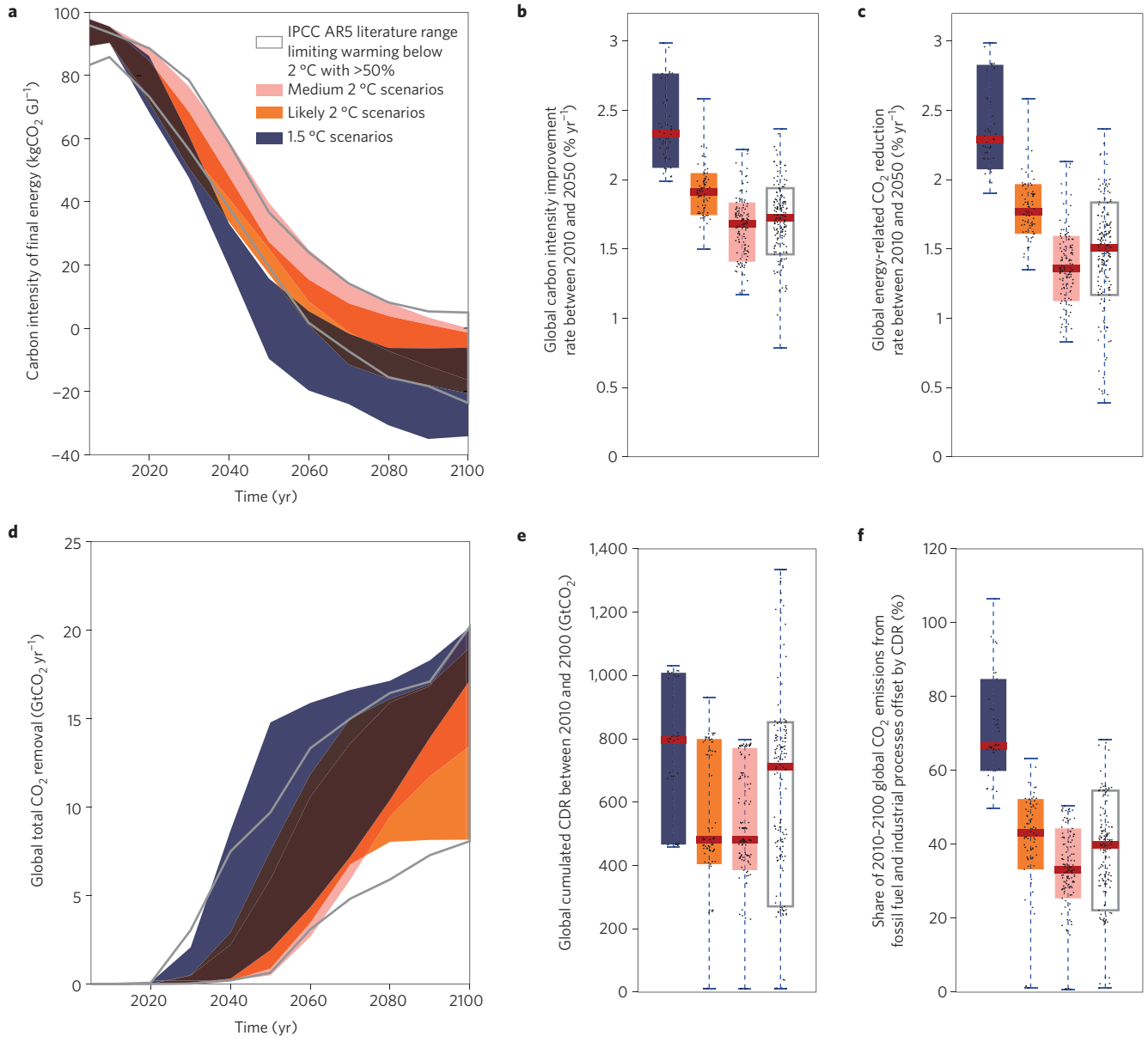


Figure 3 | Global decarbonization overview. Overview of indicators characterizing key aspects of the decarbonization of the global energy system. **a,** Carbon intensity of final energy evolution until 2100; **b,** average global carbon intensity improvements from 2010 to 2050; **c,** average reduction rate of global energy-related CO_2 emissions from 2010 to 2050; **d,** global total carbon dioxide removal CDR over time; **e,** cumulated CDR between 2010 and 2100; and **f,** share of cumulative global CO_2 emissions from fossil fuel burning and industrial processes offset by CDR between 2010 and 2100. Results are provided for selected ensembles of scenarios in line with a specific temperature limit (blue, orange and pink) including the range of scenarios available in the IPCC AR5 scenario database (indicated by grey lines). Ranges in panels **a**,**d** show the 15th to 85th percentile range. Box plots in panels **b**,**c**,**e**,**f** show the median (red line), the 15th to 85th percentile range (box) and the minimum–maximum range (whiskers). Dots represent single scenarios. Reduction rates in panels **b**,**c** were expressed as linear fractions of 2010 levels.

Energy-related emissions. The maximum amount of future cumulative CO_2 emissions is determined by the pace at which global carbon neutrality is achieved, which in turn is constrained by existing carbon-emitting infrastructure[40,41]. Figure 1 already shows that global total CO_2 emissions of 1.5 °C-consistent scenarios become net zero at around 2045–2060. A rapid and fundamental decarbonization of the global energy system by mid-century is thus required. This decarbonization is further illustrated by the evolution of carbon intensity of energy, that is, the average CO_2 emissions per unit of final energy supplied (Fig. 3a). By 2050, the carbon intensity of energy in 1.5 °C-consistent scenarios has declined towards −9.6 to 15.8 $kgCO_2$ GJ^{-1} from today's levels, which exceed 90 $kgCO_2$ GJ^{-1}. The below-zero end of carbon intensities is due to negative emissions from BECCS deployment, which are accounted towards the energy system. By contrast, in both medium and likely 2 °C scenarios, global carbon intensity in 2050 lies between 19.5 and 37.0 $kgCO_2$ GJ^{-1}.

The higher pace of the decarbonization of the energy system in 1.5 °C-consistent scenarios is also reflected in the range of carbon intensity improvement rates that are about 0.5% higher in 1.5 °C-consistent scenarios than in medium 2 °C scenarios (Fig. 3b). Together with improvements in energy intensity (here, the average amount of final energy used per unit of global economic output; Supplementary Fig. 4) from 2010 to 2050, these trends result in large annual reductions of CO_2 emissions. For instance, energy-related CO_2 emissions are reduced by 2.0–2.8% yr^{-1} in 1.5 °C-consistent

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scenarios relative to 2010 levels, compared with 1.2–1.8% yr^{-1} in 2 °C-consistent scenarios available in the IPCC scenario database (Fig. 3c). We here express annual reductions as a fraction of 2010 emission levels over time. Sometimes exponential growth rates are used to express annual reductions[22]. However, while the latter approach is well-suited to describe increasing or asymptotically declining trends, it cannot capture emission reductions of pathways that achieve net negative emissions levels at some point during the investigated period.

Disassembling accelerated decarbonization. The first step in a comprehensive transformation of the energy system is a decarbonization of the electricity system[22,42–44]. Both 1.5 °C and likely 2 °C scenarios in our set emit almost zero carbon emissions from electricity by 2050. This transformation is achieved more quickly in 1.5 °C scenarios though, with median CO_2 emissions from electricity in 1.5 °C scenarios being already about 35% (55%) lower in 2030 than in likely (medium) 2 °C scenarios (Supplementary Fig. 6a). Freely emitting fossil-based electricity generation is thus phased out earlier, and carbon-free technologies are ramped up at a faster pace. By 2030, the median share of low-carbon technologies, that is, renewables, nuclear and CCS, in electricity generation is already more than 10% higher in 1.5 °C-consistent scenarios compared with likely 2 °C scenarios (Supplementary Fig. 5a). Other aspects that foster a decarbonization of the energy system, like the share of electricity in final energy, also show an accelerated increase in 1.5 °C-consistent scenarios (Supplementary Fig. 5b).

Besides the higher near-term pace of electricity decarbonization, significantly greater efforts are required to reduce emissions during the first half of the twenty-first century from the industry, buildings, and transport sectors (Supplementary Fig. 6). For example, the transport sector is particularly hard to decarbonize owing to its current dependence on liquid fossil-based fuels combined with dispersed combustion[45]. The 1.5 °C-consistent scenarios assessed here do not show an increased share of electricity use in the transport sector compared with likely 2 °C scenarios. By 2050, in both these scenario sets about 25% (5–30%) of the energy required in the transport sector comes from electricity (Supplementary Fig. 5d), which is a massive increase from the current share of lower than 1%. Emissions are thus further reduced by other means, in particular, by demand reductions and the increased use of biofuels in liquid energy carriers (Supplementary Fig. 5c). In summary, 2050 emissions in 1.5 °C scenarios in the industrial, transport and buildings (residential & commercial) sectors are about 25%, 40% and 50% lower than in likely 2 °C scenarios, respectively. These reductions increase to 40%, 55% and 65% respectively, when compared with medium 2 °C scenarios (Supplementary Fig. 6b–d). Overall this indicates that 1.5 °C scenarios have reduced flexibility for choosing between decarbonization options and highlights the need to overcome barriers towards realizing the full mitigation potential in the transport and residential sectors[37].

Energy efficiency. Future energy demand is an important determinant of future CO_2 emissions. Dedicated energy efficiency policies could result in an acceleration of energy intensity reductions, relative to the rates observed historically, even in the absence of climate policies. In such low energy intensity scenarios, emission mitigation is less constrained than in scenarios with reference assumptions on energy intensity[11–13]. Most scenarios that are able to limit warming to below 1.5 °C exemplify such low energy intensity. The set of 1.5 °C scenarios assessed here does not include a single scenario with an average annual energy demand (between 2010 and 2100) of more than 500 EJ yr^{-1} (in terms of 'final energy'). In most 1.5 °C scenarios the average energy demand is below 400 EJ yr^{-1}, reflecting an increase from today's 350 EJ yr^{-1} to about 450 EJ yr^{-1} by 2100

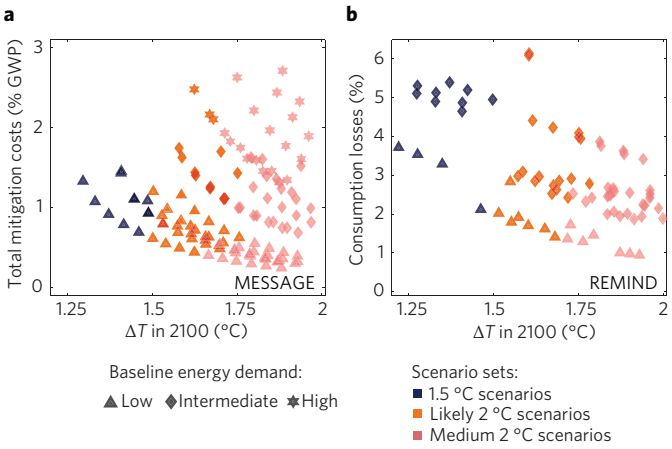


Figure 4 | Mitigation costs for 1.5 °C and 2 °C scenarios. Aggregated, discounted mitigation costs from 2010 to 2100 (discount rate 5%) as a function of median temperature (*T*) increase above pre-industrial in 2100. Scenarios are coded as a function of the underlying baseline energy-demand evolution (low, intermediate and high represented by triangles, diamonds and stars, respectively; actual demand numbers are provided in Supplementary Fig. S8) and their probability of limiting warming to particular temperature levels (pink, orange and blue). **a,** Total mitigation costs for the scenarios of the MESSAGE model; **b,** consumption losses for the scenarios from the REMIND model. The mitigation costs methodology is described in the Methods section.

(Supplementary Fig. 8). For comparison, some scenarios in our set increase global energy demand to about 900 EJ yr^{-1} in 2100 and have an average annual energy demand between 2010 and 2100 of about 600 EJ yr^{-1}. In addition, lowering energy demand and increasing energy efficiency also substantially reduces mitigation costs[11–13] (Fig. 4 and below). In line with what was found[12,13,22,46,47] for 2 °C, these results suggest that targeted measures to stimulate energy efficiency improvements are a key enabling factor for achieving a 1.5 °C target.

Carbon dioxide removal. For global CO_2 emissions to become net negative in the second half of the twenty-first century, specific technologies are used to compensate for residual CO_2 emissions from hard-to-decarbonize sectors such as transport and industry. These are known under the general term carbon dioxide removal (CDR) technologies[22,48] and comprise a wide range of specific technologies that remove CO_2 from the atmosphere, either as a side benefit or as their main activity. BECCS is a common example of such a technology that can generate so-called net negative emissions. However, important barriers to its widespread implementation still exist[49]. Alternatively, or in addition, land-use sinks can also offset emissions from fossil fuel use. In particular, if afforestation is included in the portfolio of mitigation options, the global land biosphere can act as a substantial net sink of emissions[50] but there are questions surrounding the permanence of this uptake. Other CDR technologies such as enhanced weathering of grinded rocks and direct CO_2 capture from ambient air also exist[22], but such technologies have not been accounted for in the scenarios analysed here.

BECCS and changes in land-use sinks account for a combined 450–1,000 $GtCO_2$ worth of negative emissions until 2100 in our 1.5 °C scenarios (Fig. 3d,e). The contribution of CDR is of major importance as it offsets a large share (60–85%) of the cumulative CO_2 emissions from fossil fuels between 2010 and 2100 (Fig. 3f). In both medium and likely 2 °C scenarios CDR generally offsets less than half of the fossil fuel emissions (Fig. 3f; similar to 2 °C scenarios in the IPCC scenario database). While most 2 °C-consistent scenarios

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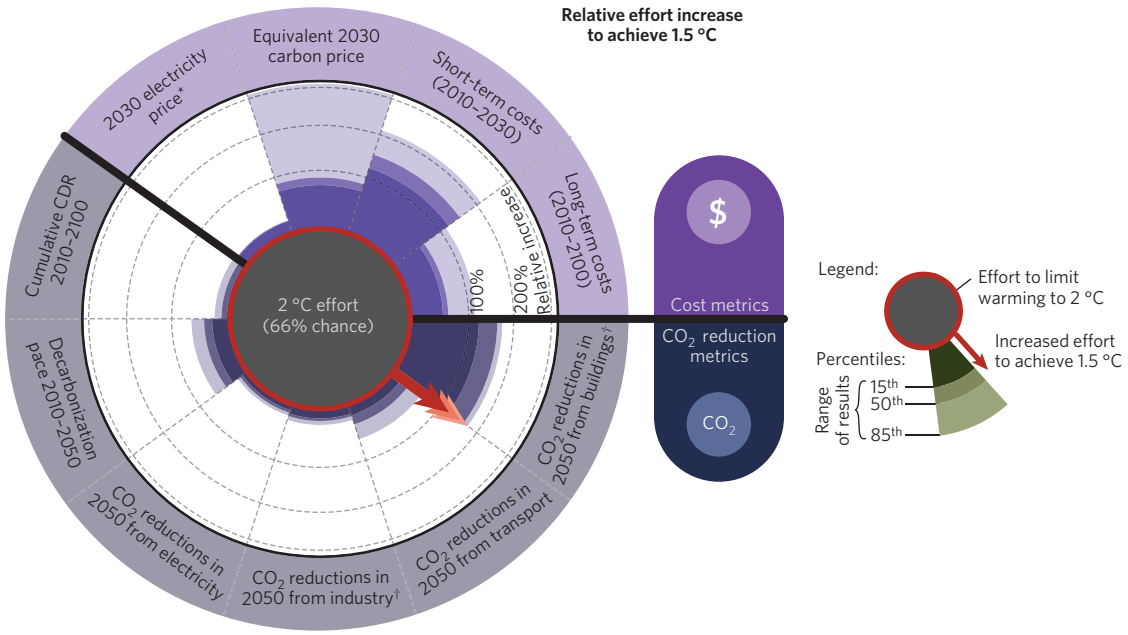


Figure 5 | Overview of the relative change in mitigation contributions or characteristics for 1.5 °C-consistent scenarios relative to corresponding 2 °C-consistent scenarios. Indicators are: long-term mitigation costs (2010–2100 aggregate discounted at 5%); short-term mitigation costs (2010–2030 aggregate discounted at 5%); 2030 equivalent carbon price level; electricity price in 2030; the total level of CO_2 removal between 2010 and 2100 (CDR); the decarbonization pace (average linear 2010–2050 rate of reductions in energy-related CO_2 emissions); reductions in CO_2 emissions from electricity from baseline in 2050; reductions in CO_2 emissions from industry from baseline in 2050; reductions in CO_2 emission from transport from baseline in 2050; and reductions in CO_2 emissions from buildings from baseline in 2050. *only REMIND provides data. †only MESSAGE provides data. All changes are provided relative to the reference case of limiting warming to below 2 °C with 66% chance. Changes relative to 2 °C scenarios with other probability levels are provided in Supplementary Figs 10 and 11.

thus also strongly rely on CDR, examples with a significantly lower or even zero contribution of negative emissions are available in the literature[11–13,43] (albeit at substantially higher costs). Importantly, in all 1.5 °C-consistent scenarios, the bulk of negative emissions are achieved in the second half of the twenty-first century (Fig. 3d). Large-scale application of BECCS or alternative CDR technologies in the second half of the twenty-first century seem indispensable for 1.5 °C scenarios, as temperatures in such scenarios do not have only to stabilize but also to peak and decline. If CDR technologies such as BECCS do not become available on a large scale and at societally acceptable costs, models[11,12] are not able to limit cumulative emissions to a level that would restrict warming to 1.5 °C in 2100. This highlights the critical importance of research and demonstration projects exploring the early implementation of large-scale BECCS to develop a real-world sense of the achievability and costs of this technology[49].

Mitigation timing and contributions

The policy assumptions that underlie the scenarios assessed here can inform us about the implications of near-term policy choices for the achievability of 1.5 °C-consistent scenarios. Previous studies[11–13], model comparison exercises[46,47,51] and the IPCC[22] have already highlighted that globally comprehensive emissions reductions starting in 2020 are instrumental for keeping the 2 °C target within reach. As indicated above, 1.5 °C scenarios have lower emissions in 2030 than 2 °C scenarios. Achieving these reductions by 2030 requires a clear and early signal, which can drive a more radical upscaling of low-carbon investments than in 2 °C-consistent scenarios, already by 2020. A longer delay of action would imply that temperatures would exceed possibly critical levels further and for longer, and that associated climate risks related to nonlinearities in the climate system response (for example, related to sea-level rise[52]) would thus be higher.

Countries have typically been subdivided in two main groups in the international climate talks: Annex I and Non-Annex I. Annex I (defined in an appendix to the Kyoto Protocol[53]) roughly represents developed countries and economies in transition (from the former Soviet Union), whereas Non-Annex I roughly covers emerging economies (such as Brazil or China) and developing countries. The distinctions between these groups are becoming increasingly less clear, for example, with some Non-Annex I countries having a higher gross domestic product per capita than some Annex I countries. Nevertheless, because of their prominence in international climate negotiations, it remains interesting to look at the mitigation contributions of these two groups. We find that, between 2011 and 2100, the cumulative amount of CO_2 that is mitigated by Non-Annex I countries (relative to an idealized 'no policy' baseline) is about two to four times larger than that of Annex I countries in low emission scenarios (Supplementary Fig. 7). The width of this range is mainly driven by assumptions about future energy demand. However, the main reasons for more mitigation occurring in Non-Annex I countries are twofold: (1) the much higher estimated baseline emissions in Non-Annex I countries, driven by population growth, economic growth and the absence of climate mitigation policies (causing estimated cumulative CO_2 emissions between 2011 and 2100 under baseline conditions to be 2 to 3 times larger in Non-Annex I than in Annex I, based on the range assessed in ref. 12); and (2) the higher mitigation potentials in developing countries at a given carbon price. In our set, the relative amount of mitigation taking place in Non-Annex I versus that in Annex I diminishes slightly but consistently when moving from 2 °C to 1.5 °C-consistent scenarios. This indicates that an increasing share of the additional mitigation required to move from a 2 °C to a 1.5 °C scenario is carried out in Annex I countries. Important to note is that absolute emissions reductions in both Annex I and Non-Annex I depend strongly on baseline assumptions about energy

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Table 1 | Key characteristics of 1.5 °C scenarios and comparison with 2 °C scenarios.

Key 1.5 °C characteristic	Detailed qualification
CO_2 reductions beyond global net zero emissions.	1.5 °C-consistent scenarios reach net zero carbon emissions globally by mid-century, 10–20 yr earlier than in scenarios consistent with only 2 °C, and show net negative emissions in the 2050–2100 period, which is not a requirement for 2 °C-consistent scenarios.
Additional GHG reductions mainly from CO_2.	The mitigation potential of non-CO_2 GHGs is often already exhausted by mitigation action for keeping warming to below 2 °C. Therefore, additional reductions in 1.5 °C scenarios are mainly from CO_2.
Rapid and profound near-term decarbonization of energy supply.	1.5 °C scenarios require a decarbonization of energy supply that is more rapid and profound than in 2 °C-consistent scenarios. Early CO_2 reductions in 1.5 °C-consistent scenarios are achieved through early reductions in the power sector (Supplementary Fig. S6).
Greater mitigation efforts on the demand side.	By mid-century, mitigation efforts in the industry, buildings and transport sectors lead to significantly lower emissions from these sectors.
Energy efficiency improvements are a crucial enabling factor for 1.5 °C.	Energy efficiency plays a critical role in low stabilization scenarios in general. Most 1.5 °C scenarios assume energy use per unit of GDP to decrease at a faster pace than historically observed, for example, owing to dedicated energy efficiency policies. In addition, there are substantial climate-policy-induced demand reductions, which are greater in 1.5 °C than in 2 °C scenarios owing to the more stringent emissions constraints.
Higher mitigation costs.	Aggregated long-term mitigation costs are higher, for example up to two times when comparing corresponding 1.5 °C and 2 °C scenario pairs. The effect on near-term costs is greater.
Comprehensive emission reductions need to be implemented in the coming decade.	The window of emissions in 2030 that still keeps the option open to limit warming to below 1.5 °C by 2100 is much lower and substantially smaller than the corresponding window for 2 °C-consistent scenarios. Diverting investments towards low-carbon technologies in the coming decade is therefore critical.

intensity improvements and other factors. Those can have a larger impact on regional emissions reductions than the variation of mitigating stringency (Supplementary Fig. 7).

Economic implications

Given the strong connection between emissions, energy use and economic activities, decarbonization efforts will inevitably affect the global economy. Relevant economic indicators of mitigation challenges include carbon prices, which quantify the marginal costs of emissions reductions, as well as aggregate long- or short-term mitigation costs.

As cheap mitigation options are already exhausted in 2 °C scenarios, higher carbon prices are required to further limit warming to 1.5 °C. For example, moving from medium 2 °C scenarios to 1.5 °C scenarios when assuming a default mitigation portfolio implies three or five times higher carbon prices in 2020, based on the analyses of refs. 11 and 12, respectively. Relative to likely 2 °C scenarios, this would be two and three times higher, respectively. Many of the 1.5 °C scenarios assessed here assumed carbon prices to be applied from 2010 onwards. Only very few scenarios are available that start ramping up carbon prices from 2020 (Supplementary Fig. 9). The additional effort between 1.5 °C and 2 °C scenarios is also reflected in an increase in the mitigation costs aggregated from 2010 to 2100 (Fig. 4). Other assumptions kept the same, achieving a 1.5 °C-consistent scenario is roughly 1.5–2.1 times more costly than achieving a corresponding likely 2 °C scenario (Fig. 5; relative to a medium 2 °C scenario this range would be 2.2–3.7).

As keeping temperatures to below 1.5 °C by 2100 requires a much faster decarbonization of the economy in the coming decades than is the case for 2 °C stabilization, the effect on near-term mitigation costs is particularly pronounced. We find that mitigation costs of 1.5 °C-consistent scenarios between now and 2030 are higher by a factor of 5.2 (4.6–7.1) compared with medium 2 °C scenarios, and by a factor of 2.5 (2.2–3.1) compared with likely 2 °C scenarios (Fig. 5). While the impact of such transformation pathways on economic growth amounts to a few tenths of a percentage point per year, and thus constitutes only a modest reduction of the average yearly economic growth rate of around 3% assumed in the models, these costs might still be a relevant barrier to their political feasibility, particularly if costs are distributed unevenly among different societal groups. At the same time, it is important to note that the mitigation cost estimates presented here do not account for the economic benefits from, for example, avoided climate damages, reduced air pollution and possibly improved energy security.

Incremental mitigation effort

Given the ongoing UNFCCC review of the long-term global goal, understanding the incremental mitigation efforts required when moving from a 2 °C-consistent towards a 1.5 °C-consistent world becomes important. Limiting warming to below 2 °C will already entail major global challenges[11,12,22,24,47,51,54,55]. The minimum requirements for scenarios in the 1.5 °C range are more ambitious than for the likely 2 °C scenarios, but contributions vary across indicators.

So far, we have focused on the general characteristics of 1.5 °C scenarios and the difference with 2 °C scenarios. To better explore the incremental mitigation effort between 1.5 °C and 2 °C, we now conduct a like-with-like comparison of pairs of scenarios (Fig. 5), that is, between a scenario limiting warming in 2100 to below 1.5 °C with 50% probability and a scenario limiting warming to below 2 °C with 66% probability during the twenty-first century, all other scenario aspects kept the same (Methods).

Along some of the dimensions, little difference exists between members of our 1.5 °C and 2 °C scenario pairs, whereas in other dimensions key differences becomes apparent. For instance, as highlighted earlier, most of the supply-side mitigation potential by 2050 is already used when aiming to keep warming to 2 °C with 66% probability. Moving to 1.5 °C thus does not push these 2050 contributions much further but relies on much stronger emission reductions on the end-use side. For example, by 2050, both the reductions in CO_2 emissions related to electricity production and in the total amount of CDR during the century show small increases compared with the much stronger additional reductions in the end-use sectors such as industry and, in particular, transport and buildings. Earlier, we also found that 1.5 °C scenarios show a significantly higher pace of emissions reductions in the coming decades, therefore near-term costs show a much higher increase than the long-term costs over the entire century. We find that the near-term electricity price, however, is only slightly affected.

Importantly, the magnitudes of change shown in Fig. 5 give only an indication of the differences between 1.5 °C and 2 °C scenario

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pairs along the different dimensions. However, mitigation challenges do not scale linearly with these differences, because their extent is also influenced by political and societal values.

Finally, we here discussed the differences between scenario pairs that were selected to meet the minimum 1.5 °C and likely 2 °C requirements (that is, limiting warming in 2100 below 1.5 °C with 50% probability, and below 2 °C during the twenty-first century with 66% probability). Scenarios exist that push these dimensions even further (for example, compare the increase in CDR between the likely 2 °C and 1.5 °C scenarios subsets in Fig. 3d with the values shown in Fig. 5). These scenarios achieve higher probabilities for limiting warming to below 1.5 °C in 2100.

In conclusion, our analysis shows that limiting warming to below 1.5 °C by 2100 comes with important challenges, some of which are similar to and some of which are much larger than those faced in 2 °C-consistent scenarios. Table 1 provides an overview of the identified similarities and differences, of which we here highlight a few.

First, as the mitigation potential for non-CO_2 GHGs is often already exhausted by mitigation action for keeping warming to below 2 °C, the burden of additional reductions in anthropogenic forcing is mainly put onto CO_2 emissions. The 1.5 °C-consistent scenarios reach global carbon neutrality by mid-century, one to two decades earlier than scenarios that are consistent only with 2 °C. Second, 1.5 °C-consistent scenarios require a profound near-term decarbonization of energy supply that is more rapid than in 2 °C scenarios. This decarbonization is achieved through early reductions in the electricity sector, and additional emission reductions by 2050 and beyond in end-use sectors, such as industry, buildings and transport. Third, energy efficiency improvements play a key role in any low stabilization scenario. There are significant differences in mitigation challenges between low, medium and high energy-demand scenarios. All 1.5 °C scenarios limit average energy demand over the twenty-first century to less than ~40% above 2010 levels, and most scenarios to no more than 15%. Such low energy demand leads to a substantial reduction of the mitigation challenges by reducing costs and increasing flexibility for decarbonizing energy supply. The key difference here is that, in many cases, returning warming to below 1.5 °C by 2100 becomes infeasible if final energy demand is not kept to very low levels (that is, below ~400 EJ yr^{-1} average from 2010 to 2100, or a maximum twenty-first-century demand level of 450 EJ yr^{-1}). Fourth, increases in costs between 1.5 °C scenarios and corresponding 2 °C scenarios are larger in the near term than in the long term. Finally, the presence of stringent near-term emission reductions in 1.5 °C scenarios points to the critical importance of early action.

International policy outlook

Pursuing the limitation of warming to below 1.5 °C by 2100 reduces the flexibility in mitigation choices almost completely, while a certain degree of flexibility was found to be available when aiming to limit warming to below 2 °C. Achieving 1.5 °C by 2100 will require immediate attention to push mitigation in every individual sector of the economy. This is strongly at odds with climate policy achievements over the past decade and thus requires a significant trend break. This elevates the importance of achieving an ambitious outcome at the 2015 UNFCCC climate summit in Paris. Failing to do so would close the door for limiting warming to below 1.5 °C by 2100. This would not necessarily foreclose the option of aiming to return global warming to below 1.5 °C at a later point in time—all 1.5 °C scenarios analysed here already show to some degree a peak and decline of temperatures. However, delaying the timing of reducing warming to below 1.5 °C would result in a longer and more pronounced temperature overshoot, entailing higher risks and more severe impacts.

Methods

Methods and any associated references are available in the online version of the paper.

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Author contributions

J.R. and G.L. designed the research with input from all authors. J.R. coordinated the research. J.R., G.L., E.K., V.K. and R.C.P. carried out the research. J.R. and G.L. wrote the first draft of the manuscript. All authors contributed to analysing the results and writing the paper.

Additional information

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence should be addressed to J.R. or G.L.

Competing financial interests

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Methods

The scenarios assessed here are drawn from three earlier studies[11–13]. For each multi-gas emission scenario the compliance with a particular global mean temperature target is computed based on a 600-member ensemble of carbon cycle and climate model simulations with the reduced-complexity carbon cycle and climate model MAGICC[17,56], version 6, in a probabilistic set-up[19]. We use MAGICC in an updated set-up such that the marginal climate sensitivity distribution is consistent with the IPCC AR4 findings[18]. Consistency with AR5 is discussed in ref. 57. For each multi-gas pathway, the temperature increase is computed relative to pre-industrial levels (1850–1875). CO_2-equivalent concentrations (C) are computed from the median total net anthropogenic radiative forcing provided by MAGICC with $C = C_0 e^{(RF/5.35)}$, in which C_0 represents the level of pre-industrial concentrations (278 ppm CO_2), RF is the total net anthropogenic radiative forcing in W m^{-2} and e is Eulers number (approximately 2.72).

Incremental challenges (Fig. 5) between scenarios with a 50% chance of limiting warming to below 1.5 °C in 2100 and scenarios keeping warming to below 2 °C during the twenty-first century with 66% probability are computed by applying the methodologies described in refs 11, 12 and extracting data that corresponds to the respective climate targets. Incremental challenges of 1.5 °C scenarios compared with scenarios that keep warming to below 2 °C with 50% or 75% chance are provided in Supplementary Figs 10 and 11. Range estimates in Fig. 5 are based on eight scenario sets created by both the MESSAGE[58] and REMIND[59] model studies and are defined in Supplementary Table 2.

Figure 4 shows two different cost metrics for scenarios provided by the MESSAGE and REMIND models, respectively. For the REMIND model, mitigation costs are given as consumption losses, expressed relative to global consumption in the baseline scenario in the absence of climate mitigation. For the MESSAGE model, total mitigation costs are provided. These direct total mitigation costs include energy-related investments, operation and maintenance costs, fuel costs, demand-side efficiency costs and non-energy mitigation costs, and are computed as the increase relative to the total system costs of the baseline scenario without climate mitigation (and with availability of the full technology portfolio). They are reported relative to gross world product (GWP) in the reference baseline. Although these metrics are not fully equivalent, they are comparable as indicators of the scale of the incremental costs incurred by more stringent climate targets.

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Corrigendum: Energy system transformations for limiting end-of-century warming to below 1.5 °C

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In the version of this Perspective originally published, the units in Fig. 3a and the corresponding main text should have read $kgCO_2\ GJ^{-1}$, not $tCO_2\ GJ^{-1}$. This error has been corrected in the online versions of this Perspective.

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behaviour of the various complexes is the same, but they exhibit profoundly different emission properties, we conclude that the specific nature of the bridge is the key to the colour switching phenomenon. It is well known that electron conduction, stabilization and delocalization on such bridging ligands depend on the geometry, energetics and structural features of the molecules[19–21]. Furthermore, use of different polymers with a higher-energy LUMO level (the HOMO level is chosen to be the same)—so that electron transfer mediated by the Ru complex cannot populate their excited state—did not result in green emission at reverse bias.

Symmetric devices with Au as anode and cathode have symmetric emission properties (that is, they show red emission at both forward and reverse bias), clearly indicating that an asymmetry in the device's charge injection behaviour is needed for the differentiation of the two possible mechanisms of light emission in the $[Ru(ph)_4\text{-}Ru]^{4+}$ PPV system. As the work functions of the ITO and Au contacts are energetically comparable, and the red/green switching behaviour is also seen when Au is replaced by Al, influences other than simple energetics must also have a role in allowing the stepwise electron transfer at reverse bias; we intend to study these influences in greater detail in the near future. □

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Fingerprints of global warming on wild animals and plants

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Over the past 100 years, the global average temperature has increased by approximately 0.6 °C and is projected to continue to rise at a rapid rate[1]. Although species have responded to climatic changes throughout their evolutionary history[2], a primary concern for wild species and their ecosystems is this rapid rate of change[3]. We gathered information on species and global warming from 143 studies for our meta-analyses. These analyses reveal a consistent temperature-related shift, or 'fingerprint', in species ranging from molluscs to mammals and from grasses to trees. Indeed, more than 80% of the species that show changes are shifting in the direction expected on the basis of known physiological constraints of species. Consequently, the balance of evidence from these studies strongly suggests that a significant impact of global warming is already discernible in animal and plant populations. The synergism of rapid temperature rise and other stresses, in particular habitat destruction, could easily disrupt the connectedness among species and lead to a reformulation of species communities, reflecting differential changes in species, and to numerous extirpations and possibly extinctions.

Many studies have examined biological changes in relation to climatic change[4,5], but generally they are concentrated in particular regions or examine a limited set of taxa. To test whether or not a coherent pattern exists across regions and taxa that is consistent with predictions of expected change, we used two types of meta-analyses on these studies: vote counting and the regression-slope model (see Methods). One advantage of meta-analyses is that a broad spectrum of findings can be combined, including those for which statistical significance has not been shown. We examined thousands of articles, including those assembled by Working Group II of the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC TAR WGII)[6]. Of these, we included in our analyses only those that (1) examined a span of at least 10 years, (2) found that a trait of at least one species shows change over time, and (3) found either a temporal change in temperature at the study site or a strong association between the species trait and site-specific temperature. Because we were looking for trends, we also excluded studies examining climatic cycles, such as North Atlantic Oscillation and El Niño/Southern Oscillation. We divided 143 studies that met our criteria into two 'tiers': those demonstrating a statistically significant trend for at least one species examined (tier 1, most of which were used as the methodological basis for conclusions in the IPCC TAR WGII[6,7]) and those in which statistical significance was not shown by the study's authors (tier 2), usually because no statistical tests were applied. We performed our analyses for each tier taken separately and for the two combined. Appendices 1 and 2 of the Supplementary Information provide the data and citations

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Table 1 **Summary statistics for meta-analyses**

	Significant species	Nonsignificant species	Combined species
Number of species changing	586	882	1,468
Number changing in expected direction	482	708	1,190
Percentage in expected direction	82.3%	80.4%	81.1%
90% confidence interval for percentage in expected direction	73.4–88.6%	70.5–87.4%	74.2–86.5%
Effect size (δ)	−0.09	−0.23	−0.23
90% confidence interval for δ	−0.12 to −0.06	−0.30 to −0.14	−0.29 to −0.17
Standard error for δ	0.0004	0.0023	0.0014
Correlation coefficient (r)	−0.05	−0.12	−0.12
90% confidence interval for r	−0.06 to −0.03	−0.16 to −0.07	−0.15 to −0.09
Standard error for r	0.0002	0.0012	0.0007

A breakdown of values for those species or groups of species that were found, in the studies examined, to have statistically significant trends for various traits and for those that were not statistically significant. In addition, values are listed for the combination of these two categories of species or species groups.

for all of the studies used in our meta-analyses.

We focused on temperature change and ignored other climatic changes, such as precipitation, because the biological effects of temperature are often better understood for most of the organisms examined. Explicitly considering drought in our analyses would have allowed us to include many more studies, particularly from the Southern Hemisphere, but attributing local droughts to globally coherent patterns of climatic changes can often be difficult. We do, however, recognize that factors influencing populations interact in complex ways: temperature can exert its influence, for example, by affecting moisture availability.

Four types of change in species' traits due to warming may be possible. First, the density of species may change at given locations, and the ranges of species may shift either poleward or up in elevation as species move to occupy areas within their metabolic temperature tolerances. Second, because many natural history traits of species are triggered by temperature-related cues, changes could occur in the timing of events (phenology), such as migration, flowering or egg laying. Third, changes in morphology, such as body size, and behaviour may occur. Fourth, genetic frequencies may shift.

Attributing observed changes in populations of plants and animals to climatic change, specifically temperature increases, is possible because we expect the trends created by the large-scale pressure of global warming to show widespread, predictable and concordant patterns of change. In addition, we expect these changes to be concentrated in areas where temperature changes are largest (that is, at higher latitudes and altitudes) and for changes to be less evident elsewhere. Climate change is only one of a long list of pressures that influence the distributions and health of populations, as well as traits such as timing of activities and processes. These other pressures (for example, habitat modification, pollinator loss and exotic species introductions) often result in localized (often around centres of human populations) or multidirectional patterns of alterations to populations of species. To document a strong role for climate change in explaining many of the observed changes in animal and plant populations, we looked for repeated examples occurring over long temporal and broad spatial scales that showed unidirectional changes predicted by our understanding of the physiological tolerances of species to temperature. The predicted result, or fingerprint, of an underlying consistent shift in a large-scale pattern shown by many species around the globe, coupled with an understanding of the possible causal mechanisms, provides confidence in attributing observed species changes to climatic change. The 85 tier 1 studies and 58 tier 2 studies found strong changes occurring around the globe in various types (taxa) of animals and plants (see Supplementary Information). The meta-analyses we used to analyse the findings of these studies were the vote-counting method[8] and the regression-slope model[9]. We applied the vote-counting method to three different categories of data: 1) the 587+ species or groups of species ('+' because some studies do not provide numbers) in tier 1 (see Methods) that show statistically significant change; 2 the 886+ species or groups of species in both tier 1 and tier 2 that show statistically nonsignificant change or where the significance was unknown; and 3) the combined species (1,473+) showing change. For all three categories, the percentage of species changing in the expected direction was around 81% with a 90% confidence interval ranging from 71% to 89% (Table 1). The meta-analysis results of effect sizes and correlation coefficients were statistically different from zero ($P < 0.05$), which means that we can reject the null hypothesis of equal change in both the expected and opposite directions. Consequently, even this fairly low-powered vote-counting meta-analysis indicates that most changes are consistent with our understanding of how temperature change influences various traits of a variety of species and populations from around the globe. Hence, we can safely state that there has probably been a discernible impact of recent global warming on animals and plants.

The actual amount of change shown can be determined for those studies that examined shifts in spring phenologies. The 61 studies that investigated the change in timing of events occurring within the

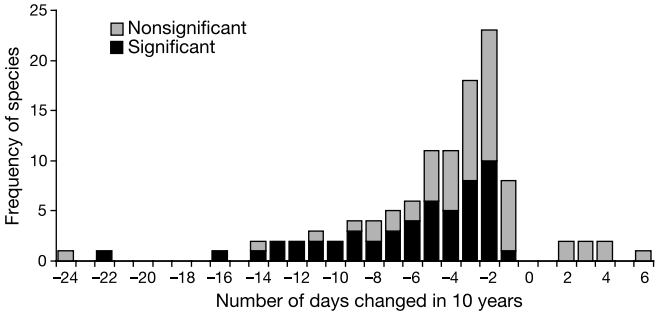


Figure 1 Frequency distribution of species and groups of species (see text) with a temperature-related trait changing by number of days in 10 years. No data were tabulated for species showing zero days changing in ten years (see Methods).

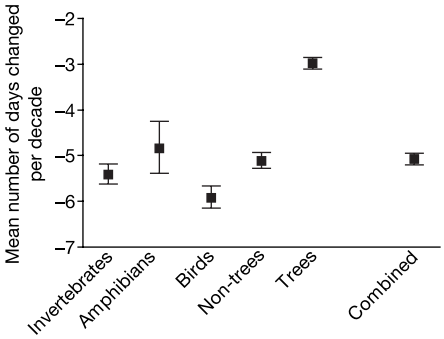


Figure 2 Means ± s.e.m. of days changed for the given groups of species. The 'Combined' category includes only those species tallied in the groups of species (that is, data for the one mammal, two fish and zooplankton are not included).

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past 50 years examined a total of 694 species or groups of species. Our meta-analyses of these species indicate that over an average decade within the past 50 years, a statistically significant change towards earlier timing of spring events has occurred. The number of days changed per decade for a given species or species group ranges from 24 days earlier per decade for the breeding of North American common murre (*Uria aalge*) to 6.3 days per decade later for the breeding of North American Fowler's toad (*Bufo fowlen*) (Fig. 1). Using the regression-slope model[9] (see Methods), we found that the estimated mean number of days changed per decade for all species showing change in spring phenology is 5.1 days earlier (s.e.m. $\pm$ 0.1; Fig. 1). When the data are grouped by statistical significance, the estimated mean of the species with nonsignificant findings is closer to zero than that for species with significant findings (-3.4 ± 0.1; -6.9 ± 0.1, respectively; negative numbers indicate an earlier shift). The latter mean is understandably earlier than the former, given that regression analysis is more powerful at discriminating steeper slopes than shallower ones. However, all three estimated averages are statistically significantly different from zero, which means that these species are all showing a marked shift towards earlier spring events.

Given that higher latitudes have warmed more than the lower latitudes in the past half century (see Fig. 3d of ref. 1), we expect phenological responses to be larger nearer the poles and not as pronounced closer to the equator. (Unfortunately, our pool of literature did not allow us to test elevational changes.) The latitudes of the spring phenology studies in the Northern Hemisphere extend from 32° N to 72° N, with one study in the Southern Hemisphere at 39°. Because of the unevenness of the location of the data (for example, a preponderance of studies in the United Kingdom), we were able to have large enough sample sizes in each group only by dividing them into two groups along 50° latitude circles. The sample size from 32° to 49.9° was 24 +, which includes the one Southern Hemisphere study. From 50° to 72° N latitude, 85+ species or species groups were examined. As expected, the estimated mean and s.e.m. of the phenological shifts (see Methods) from 32° to 49.9° latitude is smaller (-4.2 ± 0.2) than that between 50° and 72° N latitude band (-5.5 ± 0.1). These two means are statistically significantly different from each other (Kruskal–Wallis test, ($P < 0.0001$), which strongly suggests that species at higher latitudes are indeed reacting more strongly to the more intense change in temperature.

Our spring phenology data set consists of species and populations from major taxa from molluscs to mammals. We had large enough sample sizes to examine the estimated means of the phenological shifts separately for invertebrates, amphibians and birds, and for trees and other plants (Fig. 2). Four of the five means cluster around an earlier shift of 5 days, which is the estimated mean for all taxa combined. Trees, however, show an estimated mean that is later than the cluster (-3.0 ± 0.1). This estimated mean is statistically different from the other means (Kruskal–Wallis test), and the other four means are not statistically different from one another.

Our study shows that recent temperature change has apparently already had a marked influence on many species. Meta-analyses provide a way to combine results, whether significant or not, from various studies, and to find an underlying consistent shift, or fingerprint, among species from different taxa examined at disparate locations. The findings for the nonsignificant species, when aggregated, show nearly as much significant change as the group of species showing statistical significance (Table 1 and Fig. 1). Hence, for the studies we examined, the balance of evidence suggests that a significant impact of recent climatic warming is discernible in the form of long-term, large-scale alterations of animal and plant populations. For example, the average shift in spring phenology (timing) of events, such as breeding or blooming, for temperate-zone species is 5.1 $\pm$ 0.1 days earlier in a decade. The observed consistent broad-scale patterns of changes in the expected directions (80% of species showing change) strongly suggest that recent temperature trends are the most likely explanation for these observed phenomena. Clearly, if such climatic and ecological changes are now being detected when the globe has warmed by an estimated average of only 0.6 °C, many more far-reaching effects on species and ecosystems will probably occur in response to changes in temperature to levels predicted by IPCC[1], which run as high as 6 °C by 2100.

Projected future rapid climate change could soon become a more looming concern, especially when occurring together with other already well-established stressors, particularly habitat destruction. During rapid climatic changes in the past, species showed differential movements[10], rather than shifting together as suggested by many authors, including Darwin[11]. Such differential movement could result in a disruption of the connectedness among many species in current ecosystems (for example, a tearing apart of communities[7]). Research and conservation attention needs to be focused not only on global warming and each of the other stressors by themselves, but also on the synergism of several pressures that together are likely to prove to be the greatest challenge to animal and plant conservation in the twenty-first century[3,12]. Because anticipation of changes improves the capacity to manage—by acting proactively rather than reactively—it behoves us to increase our understanding about the responses of plants and animals to a changing climate. This understanding, coupled with further documentation of change, may well indicate a need for actions to modify conservation efforts and future planning to account for climate change, and to slow the projected rate of warming. □

Methods

We used results from 143 studies, each of which found some trait of a species showing a trend over a span of at least 10 years. The geometric mean of the time span for all studies was 30.3 years and the average was 34.5 years. Gaps between years were allowed. Several studies investigated more than one species and some species showed no change. The relative number of species exhibiting change compared with all species reported in the literature sources we examined is not the relevant metric we consider, because we are not trying to determine what percentage of species is responding to current climatic changes. Given that all species examined in this study (and indeed by the entire scientific community) represents only a small proportion of the total number of species that exist in the world (itself unknown), such percentage claims are untenable by any analysis. Rather, a relevant metric to detect a discernible influence of global warming on plants and animals is the fraction of those species exhibiting change that have changed in the direction expected given a temperature trend at their location. For those studies finding change in more than one species and reporting the change as an average for several species, only one entry is used in the various tests performed. For example, Fleming and Tatchell[13] reported the change in flight period of five aphids as 2.6 days earlier per decade. To be conservative, for all our analyses, this group of aphids (and all similarly grouped species) is considered as one entry, rather than as five.

Meta-analyses used

We used two types of meta-analysis, vote counting and regression slope, to determine whether changes observed are consistent with the possibility that one force, global warming, is instigating a noticeable change in species. The vote-counting method is explained in detail in ref. 8. This method is biased towards finding zero or no effect[14]—of global warming, in our case. The various studies have different sampling lengths (K_i) and so we use a geometric mean of these numbers to determine K, the mean length of years the studies examined traits of species or populations. In all three vote-counting analyses that we used—species showing statistically significant change, species showing nonsignificant change, and the combined species that showed change—the value of K is 30.

The regression-slope meta-analysis provides a way to examine directly the shift in spring phenological changes. For this method to work, the various studies examined must have used the same measurement of change, which in these meta-analyses is the number of days changed per decade. We included only those studies that examined more recent spring shifts, from 1951 to 2001. Details of the methods we used here to derive estimated slopes are given in ref. 9. Our only deviation from this formulation is that we did not include the sampling variance term in the calculation of the variance of the slope parameter. This is because most studies examined do not report some of the data necessary to derive the sampling variance. This term acts to reduce the size of the variance of the regression slope. Consequently, the variances presented here are slight overestimates, making our inferences more conservative.

Potential biases

Apart from the problems inherent in summarizing information from diverse studies of numerous subjects and methods, potential biases in the data are also of concern in analyses like ours. We do not claim that all authors of studies in the literature we cite report all

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species they observe, and there may be a bias to report primarily those species that show change. Even if there were such a bias, however, it would have no influence on our claim of a discernible impact of warming on plants and animals, because our metric of investigation is what fraction of those species that exhibit change has changed in the direction expected with local temperature trends, not what fraction of all species has exhibited change. The only way that observer bias could influence our metric would be if there were a systematic bias among the scores of studies we examine for researchers to select as study subjects only species showing changes in the direction preconceived by the authors to reflect temperature change. In addition, these many authors would have to have deliberately and systematically suppressed reporting on those species that changed in directions opposite to that expected. We find this possibility of widespread and systematic biases far-fetched, and thus believe that the metric we use is adequate for examining in an unbiased manner the existence of a discernible climatic signal in the traits of many plants and animals.

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True navigation and magnetic maps in spiny lobsters

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Animals are capable of true navigation if, after displacement to a location where they have never been, they can determine their position relative to a goal without relying on familiar surroundings, cues that emanate from the destination, or information collected during the outward journey[1,2]. So far, only a few animals, all vertebrates, have been shown to possess true navigation[3]. Those few invertebrates that have been carefully studied return to target areas using path integration, landmark recognition, compass orientation and other mechanisms that cannot compensate for displacements into unfamiliar territory[4,5]. Here we report, however, that the spiny lobster *Panulirus argus* oriented reliably towards a capture site when displaced 12–37 km to unfamiliar locations, even when deprived of all known orientation cues *en route*. Little is known about how lobsters and other animals determine position during true navigation. To test the hypothesis that lobsters derive positional information from the Earth's magnetic field, lobsters were exposed to fields replicating those that exist at specific locations in their environment. Lobsters tested in a field north of the capture site oriented themselves southwards, whereas those tested in a field south of the capture site oriented themselves northwards. These results imply that true navigation in spiny lobsters, and perhaps in other animals, is based on a magnetic map sense.

In the context of homing behaviour, an animal capable of true navigation must possess both a positional sense to determine its location and a directional or compass sense to orient in the appropriate homeward direction[6,7]. Many animals, both vertebrate and invertebrate, possess diverse compasses based on the Earth's magnetic field, the position of the Sun, patterns of skylight polarization and the positions of stars[4,8]. In contrast, few animals are known to possess the ability to determine position relative to a goal after being displaced to unfamiliar areas under conditions in which

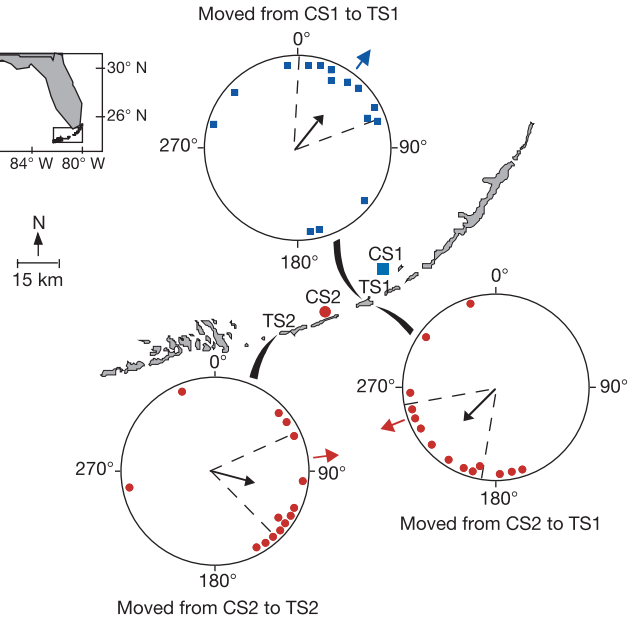


Figure 1 Orientation of displaced lobsters. Lobsters were transported by boat from two capture sites (CS1, CS2) via circuitous routes (see the text) to one of two test sites (TS1, TS2). In the orientation diagrams, each small symbol represents the mean angle of a single lobster. Blue squares indicate lobsters captured at CS1, whereas red circles indicate lobsters captured at CS2. The arrow in the centre of each orientation diagram indicates the mean angle of each group; the arrow length is proportional to the mean vector **r**, with the radius of the circle corresponding to $r = 1$. Lobsters transported from CS1 to TS1 were significantly oriented ($r = 0.51$, $Z = 3.92$, $P < 0.02$, Rayleigh test) with a mean angle of 38°. Lobsters transported from CS2 to TS1 were significantly oriented ($r = 0.65$, $Z = 5.96$, $P < 0.01$) with a mean angle of 222°. Lobsters displaced from CS2 to TS2 were also significantly oriented ($r = 0.51$, $Z = 3.89$, $P < 0.02$) with a mean angle of 105°. In all orientation diagrams, the dashed lines represent the 95% confidence interval for the mean angle. Data are plotted relative to magnetic north. The blue or red arrow outside each orientation diagram indicates the direction from the test site to the capture site. In each case, the mean angle of orientation coincided closely with the direction towards the capture site (see the text) and the 95% confidence interval encompassed this 'homeward' direction.

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FLUID INJECTION FOR SALT WATER DISPOSAL AND ENHANCED OIL RECOVERY AS A POTENTIAL PROBLEM FOR THE WIPP: PROCEEDINGS OF A JUNE 1995 WORKSHOP AND ANALYSIS

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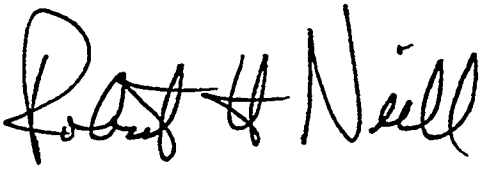
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FOREWORD

The purpose of the New Mexico Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure the protection of the public health and safety and the environment. The WIPP Project, located in southeastern New Mexico, is being constructed as a repository for the disposal of transuranic (TRU) radioactive wastes generated by the national defense programs. The EEG was established in 1978 with funds provided by the U.S. Department of Energy (DOE) to the State of New Mexico. Public Law 100-456, the National Defense Authorization Act, Fiscal Year 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and continued the original contract DE-AC04-79AL10752 through DOE contract DE-ACO4-89AL58309. The National Defense Authorization Act for Fiscal Year 1994, Public Law 103-160, continues the authorization.

EEG performs independent technical analyses of the suitability of the proposed site; the design of the repository, its planned operation, and its long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the generator sites' compliance with them; and related subjects. These analyses include assessments of reports issued by the DOE and its contractors, other federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP. Another important function of EEG is the independent environmental monitoring of background radioactivity in air, water, and soil, both on-site and off-site.



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EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant (WIPP) is a facility of the U.S. Department of Energy (DOE), designed and constructed for the permanent disposal of transuranic (TRU) defense waste. The repository is sited in the New Mexico portion of the Delaware Basin, at a depth of 655 meters, in the salt beds of the Salado Formation. The WIPP is surrounded by reserves and production of potash, crude oil and natural gas.

In selecting a repository site, concerns about extensive oil field development eliminated the Mescalero Plains site in Chaves County (U.S. DOE 1980, 2-10) and concerns about future waterflooding in nearby oil fields helped eliminate the Alternate II site in Lea County (Griswold 1977, 13). Ultimately, the Los Medaños site in Eddy County was selected, relying in part on the conclusion that there were no oil reserves at the site (U.S. DOE 1980, 2-15).

For oil field operations, the problem of water migrating from the injection zone, through other formations such as the Salado, and onto adjacent property has long been recognized (Ramey 1976). In 1980, the DOE intended to prohibit secondary recovery by waterflooding in a one mile buffer surrounding the WIPP Site (U.S. DOE 1980, 8-4). However, the DOE relinquished the right to restrict waterflooding (McGough 1983) based on a natural resources report (Brausch et al. 1982, 30) which maintained that there was a minimal amount of crude oil likely to exist at the WIPP site, hence waterflooding adjacent to the WIPP would be unlikely.

In the early 1990s, the Delaware Basin experienced a drilling boom that included oil field discoveries surrounding and underlying the WIPP Site (Broadhead et al. 1995). Salt water disposal wells are now operating throughout the area (Silva 1994; Broadhead et al. 1995) and waterflooding is just beginning with new oil field pressure maintenance programs underway (Broadhead et al. 1995).

Beginning in 1988, sudden water level rises in the Culebra aquifer to the south of the WIPP site raised questions about the water injection activities of the oil and gas industry (Bailey 1990; LaVenue 1991). LaVenue (1991) cautioned the WIPP Performance Assessment (PA) team about the yet to be determined impact of these activities. However, the WIPP PA team did not include the impact of fluid injection in the calculations citing either "low consequence" arguments for human activities adjacent to the WIPP (SNL 1991, SNL 1992) or "consequences greater than that of exploratory drilling" in the case of human intrusion (SNL 1992). In 1993, the WIPP project was again cautioned about injected oil field water fracturing the Salado Formation and migrating into adjacent properties. An oil and gas producer in southeast New Mexico had suffered a major salt water blowout as a result of a waterflood operation two miles away (Hartman 1993).

The potential impact of brine injection on the long-term performance of the WIPP prompted the Environmental Evaluation Group (EEG) to organize a June 13, 1995, workshop on the issue. This report publishes the workshop presentations (Chapter 2) and presents the author's analysis of the workshop issues (Chapter 3) based on information from the scientific literature, public records, the draft compliance application submitted by the DOE to the U.S. Environmental Protection Agency (EPA), and the WIPP specific compliance Criteria promulgated by the EPA. The workshop included presentations describing the extent of oil and gas resources, the anomalous water level rises in the Culebra Aquifer, the documented effects of water flooding on the Salado Formation, the geology of waterflooded areas in southeast New Mexico, the current petroleum production practices, the treatment of water injection by the performance assessment effort, and the need for a water flooding scenario in the WIPP PA calculations. As was intended, a number of issues were deliberated. On many issues there was no consensus. Nonetheless, the workshop was an excellent example of cooperation and open exchange of information by various federal and state agencies, private industry, the university sector, and other interested parties.

In addition to exploring the potential impact of waterflooding and salt water disposal on the WIPP, Chapter 3 identifies a number of unresolved issues. Some unresolved topics are currently in litigation between oil and gas companies and the federal government for operations adjacent to the WIPP. The issues identified in Chapter 3 include questions about a) the productive life of an oil field in the Delaware Basin, b) the extent of oil and gas reserves in unexplored areas, c) the potential for waterflooding and other secondary recovery methods, d) the volumes of water to be injected, e) the availability of water for waterflooding, f) delays in oil and gas drilling due to the presence of potash g) the true extent of potash reserves, h) evidence of communication between formations above and below the WIPP through vertical pathways possibly created by the improper abandonment of wells, poorly cemented and cased wells, degraded well casings and cement in saline environments, and i) violation of existing regulations.

This report also raises questions about how much credit for protection from out-of-zone injection the WIPP project can justify, based on state regulations unique to the Known Potash Lease Area. The state regulations were never intended to address the needs of WIPP. Rather, the state regulations were promulgated to address the concerns of the potash and oil and gas industries (LeMay et al. 1988). In light of the information presented in this report, it would seem prudent for the WIPP project to analyze the historical effectiveness of the New Mexico regulations specifically intended to address fluid injection, Rule 701, 702, and 703.

The potash companies carefully monitor activities with a potential impact on the Salado Formation. For instance, the New Mexico Oil Conservation Division held a hearing on November 16, 1995, for a proposed oil field pressure maintenance well to be located one mile from the outer boundary of the WIPP and eight miles from IMC's existing potash mine workings. At the hearing IMC expressed concern that injected water could escape or otherwise migrate from the proposed injection interval into potash bearing formations. The DOE was notified of the hearing but did not attend (LeMay 1995b). The injection well was approved to

operate at a pressure that exceeds the lithostatic pressure at the WIPP horizon.

The oil and gas industry is also concerned about the operation of injection wells in close proximity to its hydrocarbon reserves. When Yates Petroleum proposed converting an oil production well to salt water injection, another oil company objected. Mitchell Energy was concerned about excessive injection pressures and the loss of reserves as a result of injection into potential oil producing horizons (Stephenson 1991). An agreement was reached between the two oil companies (Kellahin 1991). The salt water disposal well was approved by the New Mexico Oil Conservation Division (LeMay 1991). The DOE appeared unaware that there was a salt water injection well operating within one mile of the WIPP Site Boundary and continued to list the well as an oil producing well (Arthur 1993a; Arthur 1993b; Silva 1994, 55-56; Kehrman 1995, 254, lines 18-20).

The DOE Draft Compliance Certification Application (DCCA), submitted to EPA in July 1995, did not include fluid injection in the performance assessment calculations. Citing Cranwell et al. (1990), fluid injection within the WIPP site was screened out on the basis of "regulatory guidance" (U.S. DOE 1995, 6-38), but this criterion is not found in Cranwell et al. (1990). Furthermore, DOE's expert elicitation exercise of 1990 identified industrial fluid injection as a potential human intrusion activity for the full 10,000 year regulatory period (Hora et al. 1991, Table IV-16). Fluid injection due to activities on adjacent properties was screened out on the basis of "low consequence" although the DOE draft application had no documentation to support that position (U.S. DOE 1995, SCR-72). With respect to fluid injection adjacent to the WIPP Site, the February 1996 EPA Criteria (40 CFR 194) require performance assessment to include the effects of any near future activities on lands surrounding the WIPP. A credible compliance application should include performance assessment calculations that fully consider the distinct activities of 1) fluid injection for resource recovery and 2) waste disposal activities within the site and adjacent to the site for the regulatory period of 10,000 years.

1. INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is intended to serve as a repository for the disposal of transuranic (TRU) waste generated by the defense activities of the United States Government. The WIPP is situated in the lower portion of the Salado Formation in a resource rich area in southeastern New Mexico. Natural resources in the immediate vicinity of the WIPP site include economically attractive reserves of potash, crude oil, and natural gas (Foster 1974; Keesey 1976, 1977, and 1979; Griswold 1977; Powers et al. 1978; U.S. DOE 1980; Brausch et al. 1982; Neill et al. 1983; Weart 1983; Silva 1994; Griswold 1995a; Broadhead et al. 1995; U.S. DOE 1995).

1.1 Natural Resources and Water Injection at Other Candidate Sites

The problem of natural resources and the use of water injection in the vicinity of a nuclear waste repository has long been recognized. In 1972, the Lyons, Kansas site for a proposed TRU waste repository was rejected because there were too many drill holes in the area that could not be positively located, and nearby solution mining was experiencing unexplained water losses (U.S. DOE 1980, 2-7; U.S. DOE 1993, 26). Of the three areas in New Mexico chosen for further study, the Mescalero Plains area in Chaves County was disqualified because of extensive oil field development (U.S. DOE 1980, 2-10). In the Carlsbad vicinity, two of eight sites survived the screening criteria, the current Los Medaños site and the Alternate II. However, Alternate II in Lea County was rejected for a variety of reasons including the observation that it lay adjacent to the Double X and Triple X oil fields where waterflooding for secondary recovery could occur (Griswold 1977, 13).

1.2 Oil Field Waterflooding and the Salado

Typical oil field operations include two types of water injection activities - salt water disposal and waterflooding. In a successful salt water disposal operation,

the unwanted brine is injected through a disposal well into an approved zone or zones. The production of oil, particularly in the Delaware Basin, is often accompanied by the production of large volumes of reservoir brine.

Oil production by primary recovery relies on natural reservoir energy to drive oil towards the well bore. These sources of natural energy include fluid and rock expansion, solution gas drive, gravity drainage, and the influx of water from connected aquifers. As oil, gas, and reservoir brine are produced, the natural reservoir energy is expended. Waterflooding aims to enhance crude oil recovery by restoring or supplementing reservoir energy (Willhite 1986). A successful waterflood injects pressurized water through the well bore into the oil bearing zone to force additional oil to flow towards the producing well.

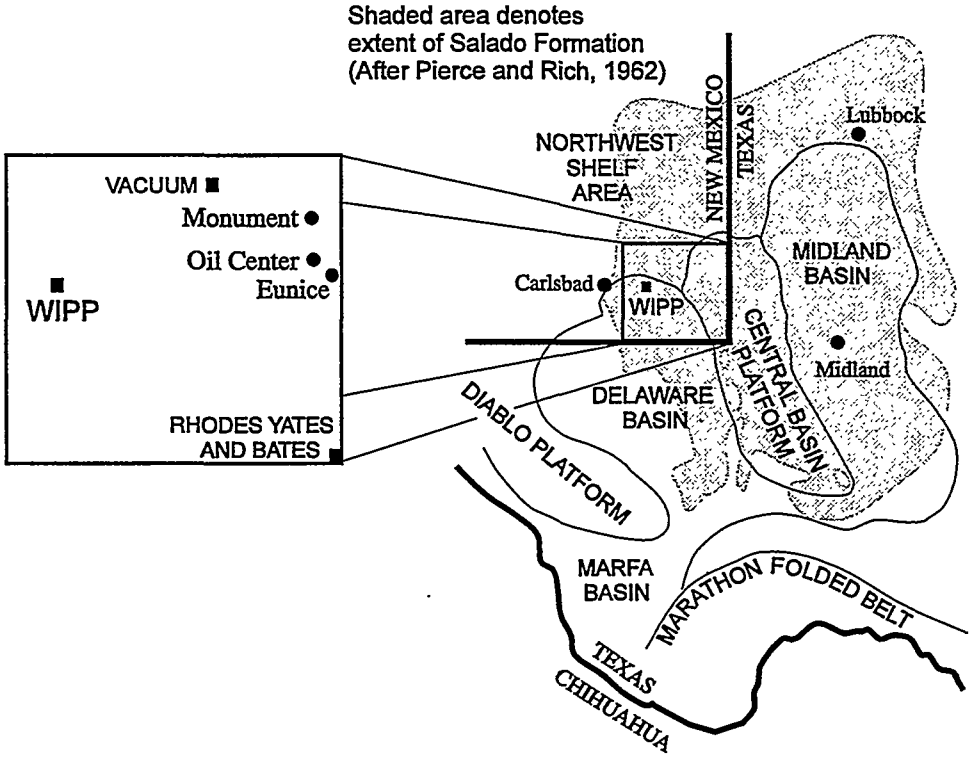


Figure 1-1. Physiographic provinces, extent of the Salado Formation, and oil field locations.

Figure 1-1 shows the locations of the physiographic zone and oil fields mentioned throughout the report. For oil fields underlying the Salado Formation, the problem of water escaping from the injection zone and migrating through the Salado Formation to adjacent properties has long been well known. For example, in a May 5, 1976, letter, Joe D. Ramey, Director of the Oil Conservation Division, advised the Secretary of the New Mexico Energy and Minerals Department (NMEMD), John F. O'Leary, of the situation:

> It has recently come to our attention that there are numerous salt water flows in and around waterfloods in Lea County... Basically the problem is that water injected at around 3600' is escaping from the injection interval, migrating upward to the base of the salt section and then moving horizontally through this section. Waterflows of 5000-6000 barrels per day and recorded surface pressures of 1600 pounds on wells outside waterflood areas are not uncommon. This had resulted in collapsed casing in several wells but the critical aspect in this is the threat of widespread contamination of fresh water.... (Ramey 1976)

In 1980, the U.S. Department of Energy (DOE) intended to prohibit secondary recovery by waterflooding (U.S. DOE 1980, 8-4) in former control zone IV - the area that now forms much of the one mile buffer outside the 4-mile by 4-mile WIPP Land Withdrawal Boundary.[1] The DOE natural resources report (Brausch et al. 1982) maintained there was a minimal amount of crude oil likely to exist at the WIPP site and did not evaluate the potential impact of waterflooding. The DOE subsequently relinquished the right to restrict waterflooding for hydrocarbon recovery in former control zone IV (McGough 1983b).

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[1]See Silva (1994) for a discussion of how previous control zone III was squared off to form the current WIPP site boundary.

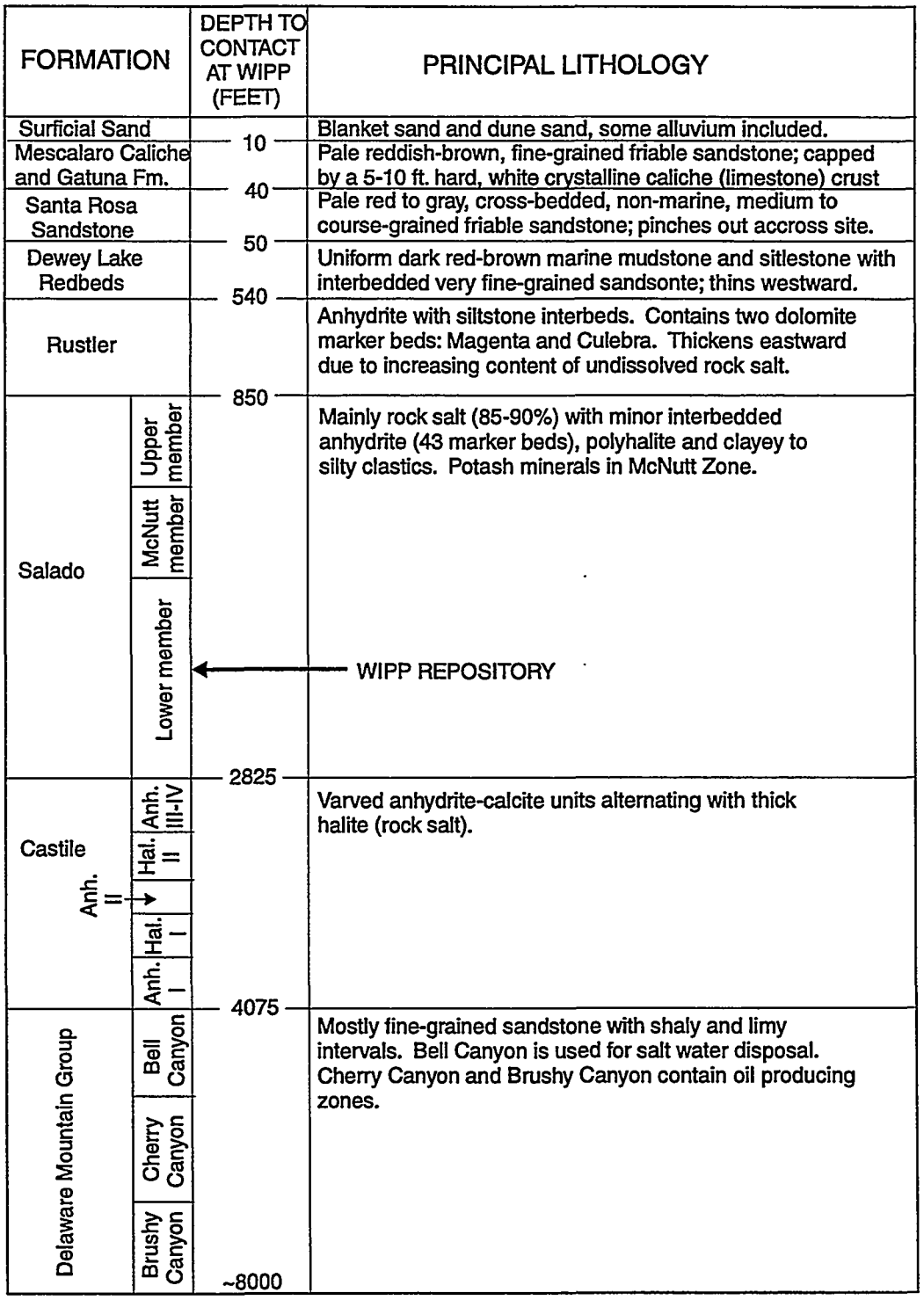


Figure 1-2. Stratigraphic cross section at the WIPP Site.

In April 1988, anomalous water level rises in the Culebra Dolomite aquifer were measured in several observation wells to the south of the WIPP site (Beauheim 1990). LaVenue (1991) conducted an investigation that raised serious questions about oil field operations. Bailey (1990), a certified professional geologist and petroleum engineer with the New Mexico State Land Office, described waterflooding problems for the Vacuum Field (an oil field overlain by the Salado and Rustler Formations) in a letter to Marsh LaVenue and suggested that the anomalous water level rises in the WIPP wells may have similar origin:

> Although the Vacuum Field, located in Township 17-18 South, Ranges 34-35 East, is located some distance northeast of the monitor wells in question, I believe the hydrogeologic setting is analogous to the well field you are currently investigating. The Vacuum Field is also overlain with Dewey Lake Red Beds and the Rustler and Salado Formations. Numerous water flows in the Salado were creating oil field casing failures and drilling and cementing problems and many people were concerned that the situation could cause contamination of the Ogallala aquifer.
>
> Discussions at the Vacuum Field Salt Water Flow Committee meetings with the Oil Conservation Division in 1986-1987 indicated that the uppermost water flow occurred at the base of the Rustler and the lowest flow occurred at the top of the Tansill Formation. The most numerous flows were found near the crest of the anticline, but flows were encountered throughout the field. Spot checking of old oil well drilling records indicate water flow drilling problems and numerous casing leak repairs in the Dewey Lake Red Beds, Rustler and Salado formation for many years. These water flows are still occurring in the Vacuum Field although at a lesser rate than during the 1970's and 1980's.

These water flows are characterized as strong, intermittent and spotty. Not all wells have encountered flows, but when they did, the flows were estimated at 1,000 - 2,000 barrels [42,000 - 84,000 gallons] per day. The flows often would last 4-5 days before stopping by themselves. The Oil and Gas Conservation District was greatly concerned about the effects of these flows and the potential for dissolution, vertical fracturing and collapse of the upper beds, and the contamination of the Ogallala aquifer.

After years of study, thousands of pressure tests, installation of pressure monitoring wells, and chemical analyses, the Water Flow Committee, decided that no one knew the origin of the early flows, or specifically where the water was stored. However, individual flows were correlated throughout the field to distinct horizons within the Salado Formation where fluid flow is facilitated along bedding planes at clastic-evaporite interfaces. Chemical dissolution of bounding salts and mechanical fracturing enable large volumes of fluids to be transported over large areas.

Chemical and isotopic analyses of the waterflow brines indicated that the waters were not naturally occurring connate waters produced by the evaporation of Permian seawater. (18)Oxygen/(16)Oxygen ratios and (18)Oxygen/Magnesium ratios indicated injected produced water as a strong candidate as a source of at least some of the water flows in the Salado Formation. Because the Vacuum waterflood project injection zone is at an approximate depth of 4320'-4720', casing leaks through the salt section are the most logical pathways for introduction of fluids into the Salado Formation (Bailey 1990).

The problem of injected water migrating "out of zone" is widespread. Bailey (1990) noted that waterfloods in and around Eunice, Oil Center, and Monument (Fig. 1-1) resulted in water flow problems through the Salado Formation. Nor is this strictly a problem of the past. Water migrating out of zone continues to plague other oil fields underlying the Salado.

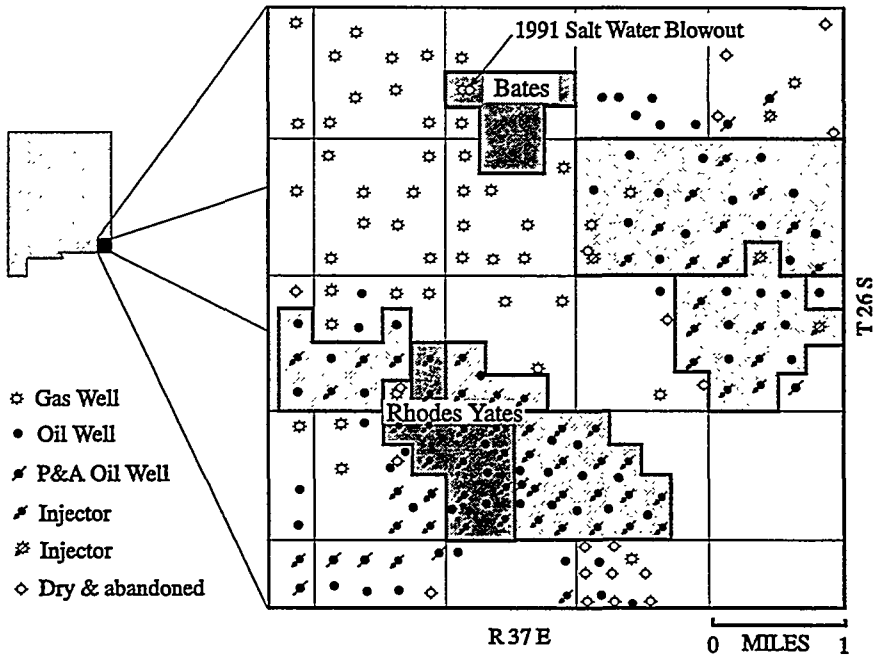


Figure 1-3. Bates Lease (Hartman), Rhodes Yates Waterflood (Texaco) and other nearby leases with injection wells.

1.2.1 Hartman vs. Texaco

On November 22, 1993, Mr. Doyle Hartman (1993) sent Sandia National Laboratories a copy of his November 17, 1993, Complaint (CIV93 1349M) filed in the Federal Court for the District of New Mexico. He stated that he furnished a copy of the complaint to familiarize Sandia "with the Lea County situation so that the proper safety measures will always be taken to preclude the occurrence of such a potentially disastrous event in the close vicinity of the WIPP site in Eddy County, New Mexico." Mr. Hartman claimed that a neighboring waterflood, Texaco's Rhodes Yates, allowed large quantities of injected water to escape out

of the approved injection zone, part and dissolve the Salado Formation, and migrate to Hartman's Bates Lease (Hartman 1993, 13).

On January 15, 1991, while drilling through the Salado Formation, Hartman experienced a salt water blowout, which flowed uncontrolled for five days. The suspected waterflood operation was approximately two miles away. On December 12, 1994, after two weeks of hearing testimony and viewing exhibits, the jury found in favor of Hartman's claim for damages. On January 20, 1995, the court ordered the defendant, Texaco, to compensate Hartman for 5.6 million dollars for damages and for value of the property injured and destroyed due to defendants' trespass (Herrera 1995).[2]

Observations of waterflows during drilling and production in waterflood areas appear to be fairly widespread in time and location. Part of the evidence gathered by Hartman's engineers included a listing of 189 waterflows reported throughout various oil and gas fields in District One[3] of southeast New Mexico for the time period from 1978 to 1993. These may not represent all the water flows encountered in this district because not every waterflow encountered during drilling is reported to the New Mexico Oil Conservation Division (NMOCD) (Lanphere and Sullivan 1994a).

1.2.2 Bass vs. United States of America

The potential impact of water flooding and fluid injection on the WIPP has been cited in the recent denial of a valid lease to directionally drill oil wells under the WIPP site from a surface location immediately adjacent to the WIPP site. In April 1993, Bass Enterprises submitted applications to directionally drill eight

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[2]The Environmental Evaluation Group understands that portions of this judgment may be in the appeal process. The Environmental Evaluation Group has no direct nor implied opinion about the case.

[3]District One of the New Mexico Oil Conservation District consists of Lea, Roosevelt, Curry, and part of Chavez County.

additional oil wells beneath the WIPP Land Withdrawal Area for the production of crude oil from the 320 acre lease (NM 02953C) in the southern half of Section 31, T22S, R31E. Drilling would have initiated on the surface outside the WIPP site Boundary, proceeded downward 6,000 feet, then deviated into the WIPP site Boundary. On August 22, 1994, the BLM denied approval to drill the eight proposed wells "due to the uncertainty of when a final determination will be made, ***and the unknown impacts from injection wells and water flooding***"[4] (Calkins 1994). On January 23, 1995, Bass Enterprises et al. (1995) filed suit against the federal government for a taking.[5]

1.3 Oil Field Salt Water Disposal

Waterflooding to promote oil recovery is not the only oil field water injection practice of concern. In a memo to LaVenue, Bailey (1990) suggested that a salt water disposal well may be the source of the water level rises south of the WIPP site:

> Because a water injection well or salt water disposal well is the most logical source of a long term or continuous increases in fluids in the monitor well (H-9), I investigated locations of such wells in the area, concentrating on any wells located north-northeast. Spot checking of production wells in the section adjacent to the monitor well had not shown a logical production well as the source of a large fluid pressure increase.... In my opinion, the most likely source of increased fluid pressure is the Devon Energy Corp. Todd 26 Federal Well #3 salt water disposal (SWD) well located northeast and upgradient of the monitor well... Since 1971,

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[4]Emphasis added.

[5]The Environmental Evaluation Group understands that this case may be in litigation. The Environmental Evaluation Group has no direct nor implied opinion with respect to this case.

2,962,402 barrels of produced water have been injected at a current average pressure of 795 psi. No records of any casing repairs are found in the OCD well files.

This observation invites the following questions. Is there evidence to indicate that the Todd 26 Federal #3 well is the source of the water level rises? How was this well completed? What is the status of this well? If the casing, tubing, and cement of this well are intact, are there other available pathways in the area providing communication? Most importantly, over the next 10,000 years, to what extent will there be salt water disposal in the vicinity of the repository?

The first four questions are explored in the EEG workshop presentations and analysis. As to the last question, salt water disposal in the vicinity of the WIPP is already taking place. As noted by Matthew Silva, Ron Broadhead, and Dan Stoelzel, in their respective presentations (Chapter 2), the Delaware wells surrounding the WIPP site produce a very high fraction of water (water cut), on the order of 50% to 70% by volume, as reflected in production records and tabulated by Broadhead et al. (1995, Table 8). Silva (1994, Figure 13) showed four salt water disposal wells within two miles of the WIPP site Boundary as of 1993. Broadhead et al. (1995, Table 7) tabulates ten salt water disposal wells and two pressure maintenance wells within the nine township area surrounding the WIPP as of 1994.

1.4 Oil Field Brine Disposal and the Potash Industry

The issue of salt water disposal in the Delaware Basin appears to be of concern to members of the potash mining industry, which also operate in the Salado Formation. On November 19, 1993, representatives from Bass Enterprises Production Company, an oil company, met with representatives from Western Ag-Minerals Company, a potash mining company, to discuss the Bass proposal to operate a brine injection well two miles west of the WIPP site. Western Ag was concerned about its substantial potash reserves surrounding the well location.

Rather than rely solely on state regulations to protect their portion of the Salado Formation, Western Ag outlined twelve additional operating provisions that would satisfy their concerns (Heinen 1994). The twelve provisions included notification of any request to increase injection pressure above 765 psi, immediate notification of tubing, casing, or packing failure and cessation of injection until the problem is corrected, an annual chemical analysis of injected brine, an annual test to determine migration of brine into other formations, and specifications for well abandonment.

1.5 Well Abandonment

Concerns about improper abandonment of wells appear to be justified. As discussed by Silva (1994), inadequate practices on U.S. Bureau of Land Management (BLM) properties are documented (U.S. DOI 1989, 1990; Baier 1990). A 1989 evaluation (U.S. DOI 1989) by the Inspector General for the U.S. Department of Interior identified considerable problems on the BLM properties resulting largely from "violations of existing regulations" (U.S. DOI 1989, 4). The report cited problems with wells in BLM's Carlsbad Area (U.S. DOI 1989, 6-7)

In arguing a difference between exploratory and development wells[6], the DOE has also brought the problem of improperly abandoned oil and gas wells to the attention of the EPA. As the DOE Carlsbad Area Office noted:

> Development wells are generally abandoned only after many years of production. Many development wells change ownership several times during their operational lifespan, and may not produce continuously. They may ultimately be abandoned improperly (Dials 1994, Supplemental Information to Options 2, 4 and 3, 12).

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[6]For other views on well definitions see Neill 1995; Vaughn 1995; Carroll and Bogle 1996; also Gorenflo vs Texaco, 566 F. Supp. 722 (1983); Sun vs. Jackson, 715 S.W. 2D 199 (1986) and 783 S.W. 2d 202 (1989).

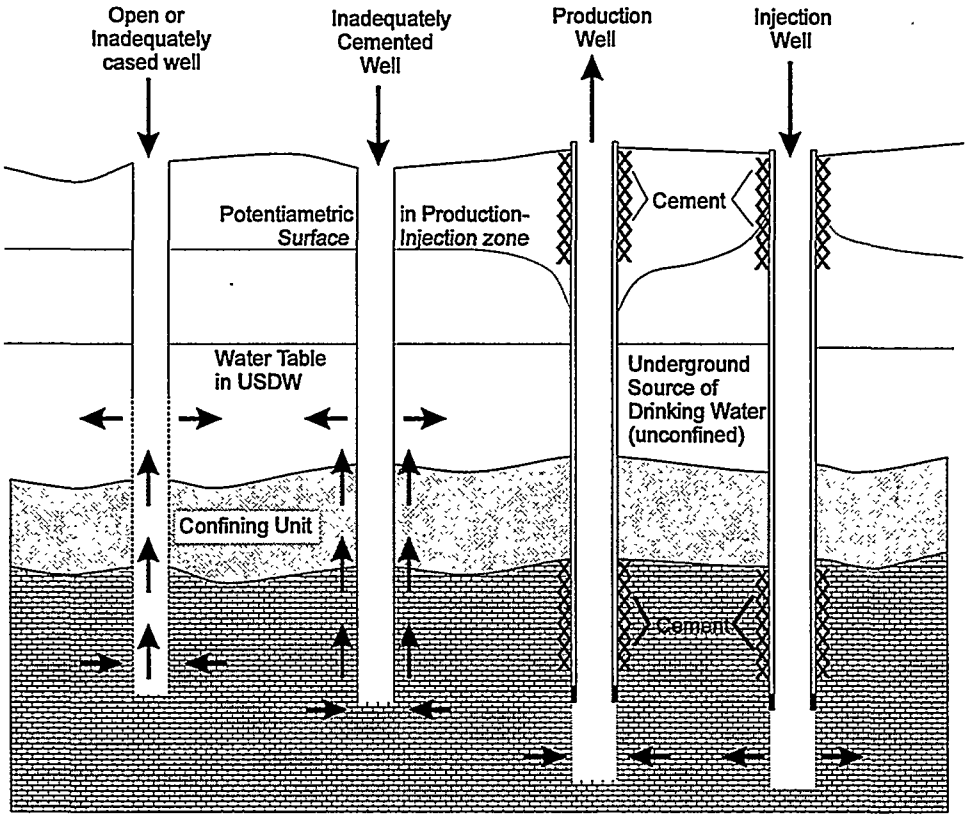


Figure 1-4. Upward flow from underlying hydrocarbon-producing zone to an underground source of drinking water through inadequately plugged wells. After Kreitler et al., 1994.

Improperly abandoned wells, in the vicinity of oil field injection wells, can serve as a pathway for contamination of underground sources of drinking water. The Texas Bureau of Economic Geology, with funding from the American Petroleum Institute, designed a method for use by regulators and operators to identify such areas (Kreitler et al. 1994).

In developing the method, Kreitler et al. (1994 pp. 64, 77) plotted the estimated density and distribution of oil field brine injection wells, as shown in Figure 1-5, and abandoned wells, as shown in Figure 1-6, throughout the greater Permian Basin, which includes the Delaware Basin.

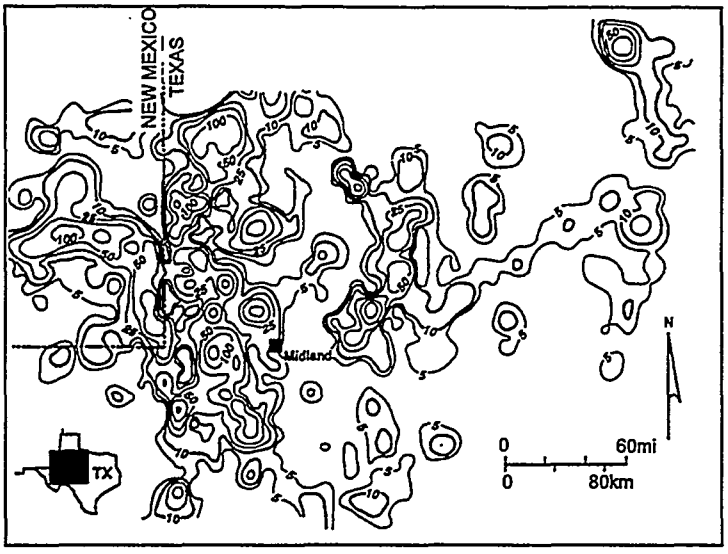


Figure 1-5. Density of Class II injection wells at 0.1°× 0.1° scale. After Kreitler et al. 1994.

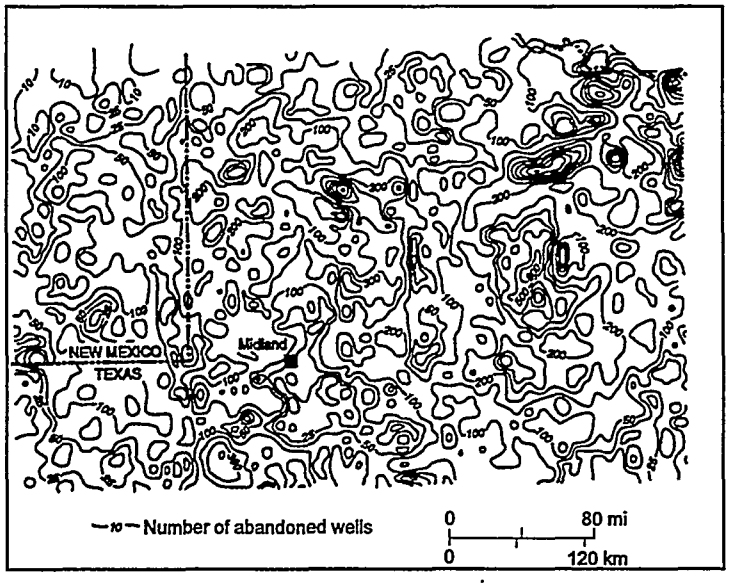


Figure 1-6. Estimated distribution of abandoned wells at 0.1°× 0.1° scale. After Kreitler et al. 1994.

They found that the most extensive area of upward hydraulic gradients occurs in the eastern Delaware Basin, Central Basin Platform, and western Midland Basin. Residual mapping indicates upward gradients with hydraulic head differentials as large as 6,000 ft (1,800 m) (Kreitler, et al. 1994, 73-74).

As part of their study, Kreitler et al. (1994) also offered insight into the problem of abandoned wells completed through salt formations. They note that in addition to less stringent construction and abandonment standards in past decades, the mechanical degradation of older wells may also reflect lengthy periods of exposure to corrosive brines. In the Permian Basin, wells that pass

through a larger number of saline units are of particular concern (Kreitler et al. 1994, 76). LaVenue also commented on 20 to 30 years of exposure to the corrosive saline environment promoting a leak in the casing and/or degrading the grout holding the casing in place (LaVenue 1991, 2). This is consistent with the DOE position that the highly saline environment of some units can promote rapid corrosion of well casings and may result in fluid loss from wellbores (U.S. DOE 1995, SCR-73). All well casings to be abandoned in the WIPP vicinity will be exposed to more than two thousand feet of salt, not only in the Salado Formation, but also in the Castile Formation, a formation unique to the Delaware Basin. It seems prudent to assume saline environments promote rapid corrosion of well casing (Kreitler et al. 1994, 76; LaVenue 1991, 2; U.S. DOE 1995, SCR-73), existing regulations are violated (U.S. DOI 1989), and wells are improperly abandoned (U.S. DOI 1989; Dials 1994). Given these observations, do the existing and yet to be drilled wells in the vicinity of the WIPP represent viable vertical pathways for the upward migration of injected fluids either into the interbeds of the Salado Formation or into overlying aquifers such as the Culebra, the Magenta, and the Dewey Lake Redbeds?

1.6 WIPP and Performance Assessment

To proceed with TRU waste disposal, the WIPP Land Withdrawal Act requires the DOE to receive certification from the EPA that the facility is in compliance with the EPA radioactive waste disposal regulations (U.S. EPA 1985; 1993, 40 CFR 191) including containment and assurance requirements. This requires analyses that the probability and amount of radionuclides released to the accessible environment over the next 10,000 years will not exceed limits specified in the EPA Standards. The performance assessment (PA) calculations published to date have identified future drilling for oil and gas reserves as an event that could disrupt the repository and release radionuclides in excess of the standards (SNL 1992, 4.1.2). The calculations have not addressed the impact on WIPP's performance of the oil and gas industry practices of salt water disposal and

waterflooding for enhanced oil recovery - two expanding activities now underway in the vicinity of the WIPP.

The 1991 DOE PA stated that such fluid injection could be eliminated from consideration in performance assessment on the basis of low consequence:

> The effects of injection wells on groundwater flow in units shallower than the Salado Formation is likely to be negligible. Units selected for injection will be thousands of feet deeper than the Rustler Formation, which is the most likely path for the groundwater transport of radionuclides to the accessible environment. The low permeability Bell Canyon, Castile, and Salado Formations are approximately 4,000 feet (1,220 meters) thick at the WIPP (Powers et al. 1978), and these low-permeability units will isolate flow in the Rustler Formation from the pressure increases in the much deeper units caused by the injection of fluids (SNL 1991, 1:4-36).

This explanation appears to be inconsistent with salt water disposal practices in the Delaware Basin, the observed water level rises in the Culebra, LaVenue's analyses (1991), and Bailey's comments (1990).[7] Records indicate that every salt water disposal well within the nine township area surrounding the WIPP injects into the Bell Canyon Formation (see Broadhead et al. 1995, Table 7). Hence, the Bell Canyon is not serving as an impermeable layer. Further, LaVenue's (1991) analyses indicated that the Bell Canyon Formation, which is below the WIPP horizon, is already in communication with the Rustler Formation, which is above the WIPP horizon. Hence, thousands of feet of vertical separation by

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[7]Despite a January 28, 1991, distribution to the WIPP PA Department, the memos of LaVenue (1991), Bailey (1990), and Ramey (1976) are not referenced in either the December 1991 PA publication or in the December 1992 PA publication.

impermeable layers of salt do not appear to be isolating the Rustler from the fluid injected into the deeper units.

The 1992 PA also did not calculate the effect of adjacent fluid injection on performance assessment, maintaining that injection wells that do not penetrate the repository can be screened out on the basis of low consequence despite the 1976 Ramey memo, 1990 Bailey memo, and the 1991 LaVenue memo, and public records on fluid injection practices in the Delaware Basin.

With respect to any human related activity within the site, including fluid injection, the 1992 PA introduced a new criteria not found in Cranwell et al. (1990) for screening events and processes (SNL 1992, 2:4-3 to 4-4). The 1992 PA stated that the EPA regulations did not require the impact of fluid injection to be evaluated. The WIPP PA Department's interpretation (SNL 1992, 2:4-3) of the non-binding guidance for the disposal of transuranic waste (SNL 1992, 2:4-4) advances the argument that disruptive human activities, such as fluid injection, need not be considered because the consequences are greater than that of exploratory drilling (SNL 1992, 2:4-4). The impact of a future disposal well was limited to drilling and the consequences were assumed to be identical to drilling an exploratory well (SNL 1992, 2:4-4).

1.7 Issue

WIPP is surrounded by new oil producing wells. Many more are planned but have been delayed due to the presence of potash (Woodard 1992; Burski 1994). Oil production is accompanied by salt water injection either for salt water disposal or waterflooding. Forcing large volumes of such brine into the designated formation requires energy in the form of fluid pressure (force per unit area). Brine migration, with energy in the form of pressure, is the same mechanism by which radionuclides can be carried out of the repository and away from the WIPP site.

The potential impact of brine injection on the long-term performance of the WIPP prompted the Environmental Evaluation Group to organize a June 13, 1995, workshop on the issue. The workshop included presentations describing the extent of oil and gas resources, the anomalous water level rises in the Culebra Aquifer, the documented effects of water flooding on the Salado Formation, the geology of waterflooded areas in southeast New Mexico, the current petroleum production practices, the treatment of water injection by the performance assessment effort, and the need for a water flooding scenario in the WIPP PA calculations. As was intended, a number of issues were deliberated. On many issues there was no consensus. The workshop did not address the impact of solution mining of potash surrounding the WIPP or the disposal of potash brine.

2. WORKSHOP PRESENTATIONS

The presentations made at the June 13, 1995, workshop are contained in this chapter. A synopsis of each presentation, distributed by the authors at the workshop, is followed by their presentations. As with any verbal dialogue, some paraphrasing of the presentations was necessary. Nonetheless, every effort was made to preserve the message of the presenters and the thrust of the questions and answers. Also, some figures, most of which were provided by the authors on diskette, required modification from their overhead format into a report format. The cooperation, patience, and understanding of the presenters and participants in addressing these difficult, but important issues, is appreciated.

2.1 R.H. Neill - Opening Statement

All of us are extremely pleased to see this large turnout for this technical workshop. I think it is a good example of the cooperation between the various federal and state authorities with representation from the Department of Energy, the Environmental Protection Agency, the Bureau of Land Management, the National Academy of Sciences, the New Mexico Environment Department, the New Mexico Oil Conservation Division, the New Mexico Bureau of Mines and Mineral Resources, Sandia National Laboratories, Oklahoma University and, of course, the Environmental Evaluation Group.

It is interesting to step back a moment to evaluate our efforts in performance assessment in predicting the behavior of the repository. The focus has been on existing fluids, whether it is the interstitial brine within the Salado or the large brine reservoirs associated with the Castile Formation or the two dolomitic aquifers above the repository horizon and in the perched water aquifer in the Dewey Lake Redbeds. We are now looking at the impact of fluid injection into nearby formations on the long-term behavior of the repository — perhaps from three different standpoints, although we will only be looking at two today. The first is to enhance the recovery of oil. The second is on salt water disposal, which

would be another reason for injecting fluids. The third might well be, in the future, to look at solution mining for potash, although we are not going to address that issue here today.

It might be helpful to mention a few things that we are not going to do today - to put everyone at ease. We are not going to address the legal issues associated with any court cases that have occurred, are pending, or will occur. Specifically, I'm referring to the Hartman vs. Texaco case. There is some very interesting, relevant, technical information associated with that case, but in no way should this workshop be construed as reopening the legal issues associated with that case. I want to make that quite clear.

We also are not going to be able today to determine the consequences of the impact of some of these actions. And although we can get some insights, perhaps, on the probability of events, one is not going to be able to determine the impact.

We look forward to each of us speaking as individuals — no one is being quoted on behalf of their agency. And also none of us have come here with a preconceived position on these issues.

I thought it might be important to those who are familiar with the performance assessment approach to acknowledge the uniqueness of the WIPP in the context that it is the only repository under consideration where there are substantial natural resources - oil, gas, and potash. And for those of you who are not in the business of performance assessment, in order to bring waste to WIPP it is necessary to be able to predict the behavior of these transuranic wastes over 10,000 years and convince EPA of the validity of those calculations and analyses. The way this is done is to come up with scenarios on how this could occur, design a model and then write the equations governing that, whether it is conservation of momentum or mass, conservation of radioactivity, the driving force, solve the equations, and then estimate the amount that arrives at the accessible environment in 10,000

years. You then look up the release limit table of the EPA standard. If the postulated releases are greater than the limits, you have problems. If they are less, you are home free.

On the current schedule, DOE expects to complete all this work by January 1997. We note that the deadline for the models is as early as September 1995, the end of this summer.

If we consider the 4-mile by 4-mile area of the WIPP site, the question comes up regarding the injection of fluids at depths greater than 4,000 feet outside the WIPP site. If by some mechanism, there is vertical movement of the brines or the fluids outside the repository, can this induce hydrofracturing in the Salado for a distance of 2 miles laterally to the repository, which may in turn flood the repository? And the question is, could this have a role in moving radionuclides laterally to the accessible environment, and exceed the EPA limits?

In terms of the location, the injection, and the timing, one can look at it in perhaps four different ways. The first is on the operational consideration of the time period from minus 20 years to t equals zero, and outside of the 4 mile x 4 mile area where this could have some potential effect on the hydrogeological real estate associated with the repository. The second is a period from T=0 to T=100 years where institutional control would prevent anyone from injecting fluids within the 4 mile x 4 mile area. The third might be a period from 100 years to several hundred years; that is not specified in the EPA criteria but it is presumed that one could take steps during that time period to prevent the injection of fluids. And the fourth is when knowledge of the repository is lost at some future date, and one could have brine injection occurring in the 4 mile x 4 mile site. We are not going to focus that much on the fourth one today, because we have some people that are able to contribute in a major way on the first three.

2.2 Evaluation of Oil and Gas Resources at the WIPP Site

Ronald F. Broadhead[1], Fang Luo[1], and Stephen W. Speer[2]

[1]New Mexico Bureau of Mines and Mineral Resources

[2]Independent Geologist, Roswell, New Mexico

2.2.1 Synopsis

Rigorous, quantitative estimates were made of oil, natural gas, and natural gas condensate resources that exist beneath the 16 mi^2 area of the WIPP land withdrawal area and an additional one-mile wide study area around the WIPP site. Calculations were made for resources that are extensions of known, currently producible oil and gas resources thought to extend underneath the WIPP land withdrawal area with reasonable certainty (probable resources). Qualitative estimates were also made of oil and gas that may be present in undiscovered pools and fields beneath the WIPP land withdrawal area (possible resources). Possible resources were not quantified.

Probable resources consist mostly of oil and associated gas in Permian strata and nonassociated gas and gas condensate in Pennsylvanian strata. Currently, most oil and associated gas production in the vicinity of the WIPP site has been obtained from sandstone reservoirs in the Delaware Mountain Group (Permian) at depths of 7,000 to 8,000 ft. Sandstones and carbonates in the Bone Spring Formation (Permian) at depths of 8,000 to 11,000 ft and carbonates in the Wolfcamp Group (Permian) at a depth of approximately 12,000 ft are secondary oil reservoirs. Carbonates in the Strawn Group (Pennsylvanian) at a depth of approximately 13,000 ft are secondary, but important, reservoirs of gas and light oil or condensate. Most nonassociated gas and condensate production in the vicinity of the WIPP site has been obtained from sandstone reservoirs in the Atoka and Morrow Groups (Pennsylvanian) at depths of 13,000 to 14,000 ft.

Probable oil and condensate resources within the boundaries of the WIPP land withdrawal area are 12.3 million bbls of oil and gas condensate recoverable by

primary production methods and an additional 6.4 million bbls of oil potentially recoverable by secondary recovery with waterfloods (Table 1). Probable resources within the one-mile wide additional study area surrounding the WIPP land withdrawal area are 22.9 million bbls oil and gas condensate recoverable by primary production methods and an additional 13.8 million bbls of oil potentially recoverable through waterflooding.

Probable gas resources within the boundaries of the WIPP land withdrawal area are 186 BCF gas (Table 1); 89% of this gas is nonassociated and will be produced from the deep Atoka and Morrow reservoirs. The remainder is associated gas, most of which will be produced from relatively shallow reservoirs in the Delaware Mountain Group. Probable gas resources underneath the one-mile wide additional study area surrounding the WIPP land withdrawal area are 168 BCF gas; 79% of this gas is nonassociated and will be produced from the deep Strawn, Atoka, and Morrow reservoirs.

In addition to probable resources, there are significant possible resources of oil, gas, and gas condensate beneath the WIPP land withdrawal area and the additional study area.

These will be oil and associated gas in untapped sandstones of the Delaware Mountain Group in largely unexplored and unevaluated sandstones and carbonates of the Bone Spring Formation, and in carbonate reservoirs in the Wolfcamp and Strawn Group. Possible resources of nonassociated gas and gas condensate will occur in sandstone reservoirs in the Atoka and Morrow Groups and in the pre-Pennsylvanian section (Siluro-Devonian and Ordovician strata). The elusive nature of possible resources makes their quantification difficult or impossible for an area of limited extent such as WIPP.

2.2.2 Presentation by Ron Broadhead

The New Mexico Bureau of Mines and Mineral Resources (NMBM&MR) contracted to evaluate the resources under the WIPP Site and an adjacent area extending one mile beyond the WIPP Land Withdrawal Area. The evaluation included oil, gas, and other mineral resources.

One purpose of the work was to estimate the total of proven and probable oil and gas resources that could be obtained by primary and secondary recovery. With respect to oil and gas, the WIPP area remains essentially undrilled. Estimating resources is a geological task.

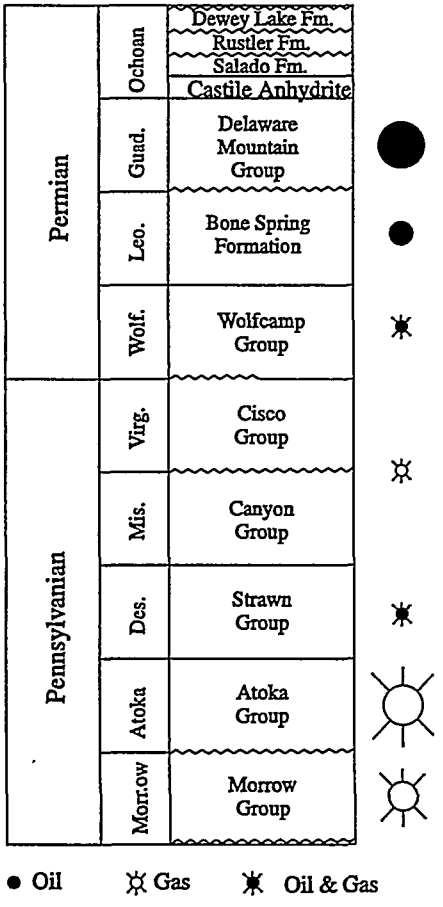


Figure 2.2-1. Productive oil and gas formations in the vicinity of the WIPP Site. Adapted from Broadhead et al. 1995.

The DOE needed a scientific, unbiased, third party estimate of the oil and gas resources. The principal data sources were well records on file at the New Mexico Bureau of Mines and Mineral Resources: Petroleum Information, Midland Oil Scouts Association, the Bureau's Niell Wills Collection, Bureau data gathered through the years, official state data from the New Mexico Oil Conservation Division, data from the U.S. Bureau of Land Management and the U.S. Geological Survey, an extensive collection of electrical logs, and the official production data reported to the State.

2.2.2.1 WIPP Area Description

Figure 2.2-1 shows the principal oil and gas producing formations within the WIPP

Site Area and surrounding areas. The principal oil production is shown by the solid circles and the principle gas production is shown by the open circles with the spikes. The major oil producing group in the area is the Delaware Mountain Group followed by the Bone Spring. There is a some production from the Wolfcamp, Cisco, and Canyon Group. Most of the gas production comes from the Atoka and Morrow Groups.

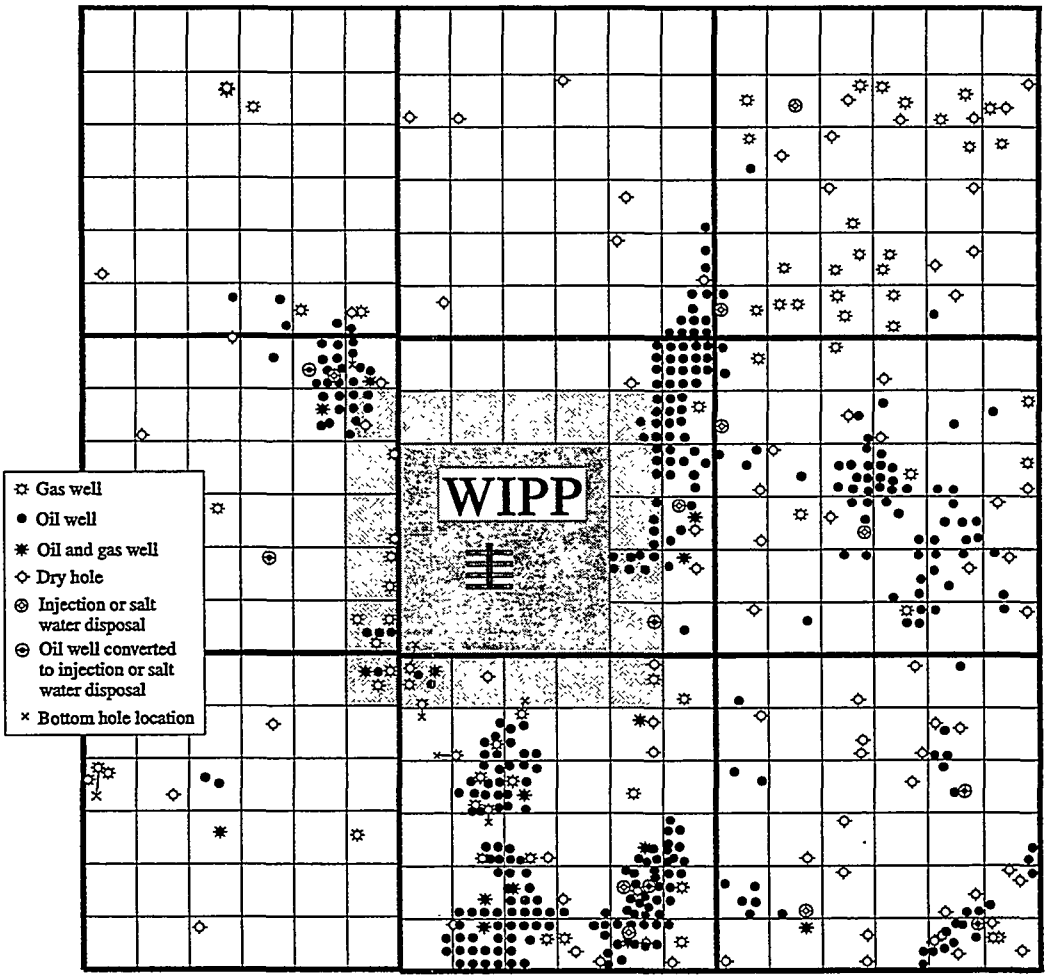


Figure 2.2-2. Oil, gas, and injection wells at WIPP Site, one-mile additional study area, and nine-township project study area.

Figure 2.2-2 shows the four mile by four mile land withdrawal area, the additional one mile wide study area, and the total nine township study area. Solid circles

represent productive oil wells at the close of 1993, or early 1994. The open circles with the eight spikes are productive gas wells. The open circles with (four) spikes are non-productive. There is only one well that produces from under the WIPP Land Withdrawal Area. That is the Bass well in the southwestern part of section 31. That deviated well was directionally drilled under the Land Withdrawal Area. Most of the oil wells produce from the Delaware Mountain Group and most of the gas wells produce from the Atoka and Morrow Groups. A couple of the wells along the western edge of the WIPP produce from the Strawn Group.

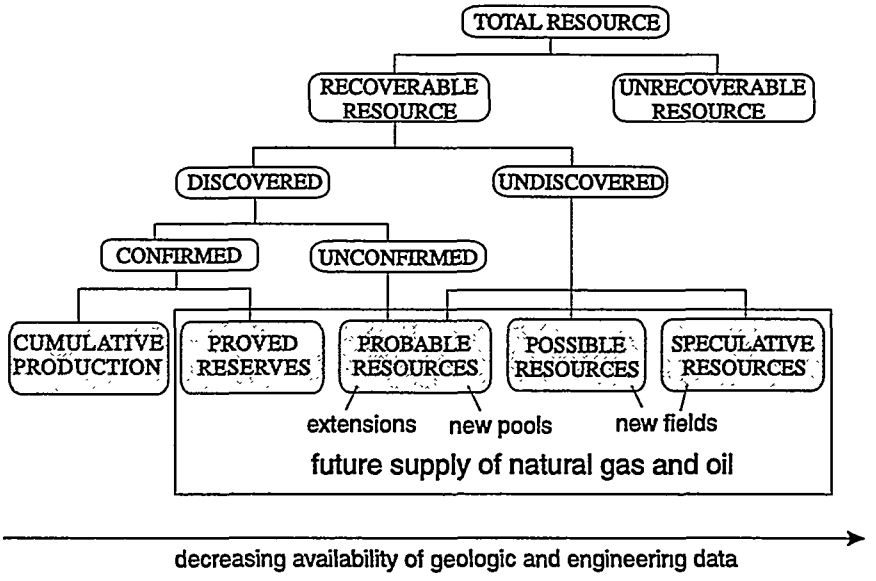


Figure 2.2-3. Oil and natural gas resource categories. From Potential Gas Committee (1993).

2.2.2.2 Method of Assessing Resource Potential

What was estimated and what was not estimated? Figure 2.2-3 illustrates the classification scheme of the Potential Gas Committee of the Potential Gas Agency. This classification can be applied to oil as well as gas. The total resource can be divided into recoverable and unrecoverable resources. The unrecoverable resource represents that which can not be taken from the rock. The recoverable resource

includes the discovered and undiscovered. The numerical estimates are based on that which is discovered. Discovered can be divided between confirmed and unconfirmed. Confirmed is divided between cumulative production and proved reserves. Cumulative production is obviously that which has been produced. Proved reserves are those reserves in known identified traps and accumulations that can be recovered by existing wells. Note there is only one well which produces from within the WIPP Land Withdrawal Area. Hence, there are very little actual proved reserves under the WIPP itself. In the additional study area there are several producing wells.

Most of the estimates included probable reserves. · Probable reserves are extensions of known petroleum accumulations that have been discovered. Those are reserves on the flanks of the existing, known accumulations.

Some qualitative assessment of possible reserves was made, but a quantitative assessment of possible reserves was not made. Possible reserves are untested traps, deeper or intermediate pools that have not been drilled, and have not been proven to be productive.

2.2.2.3 History of Drilling

As to the drilling history in this area, Figure 2.2-4 shows that through the 1920s, 30s, 40s, and 50s, drilling bumped along at no wells per year or maybe one well per year. Shallow wells were drilled down to 4,000, 5,000, or 6,000 feet and the wells proved to be non-productive. From the 1960s through the 1980s, there were little spurts of drilling within the nine township area surrounding the WIPP. There were some discoveries of oil but most were discoveries of gas. Around 1990, there was a big increase in drilling - *the Delaware Play*. Delaware Pools were discovered at Livingston Ridge, East Livingston Ridge, Los Medaños, Cabin Lake and a number of other smaller Delaware fields. This occurred throughout the Delaware Basin, not only around the WIPP Site, but throughout southeast New Mexico.

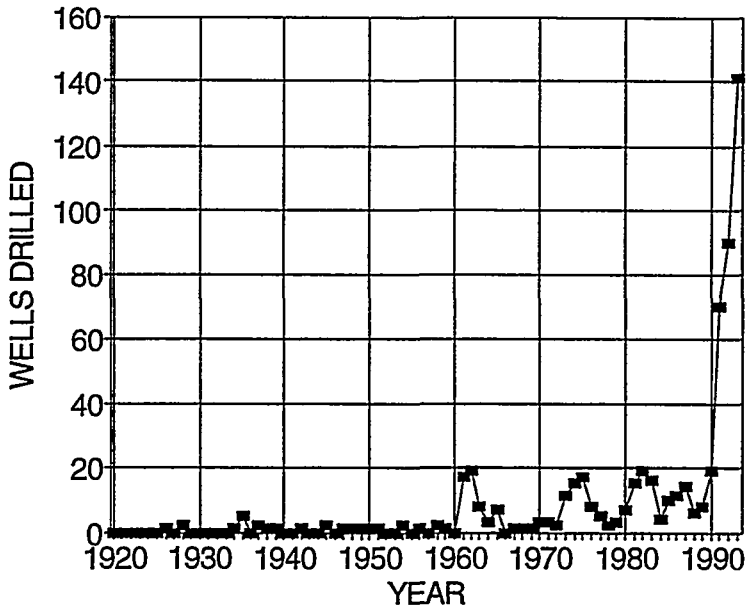


Figure 2.2-4. Annual number of oil and gas wells completed in the nine-township area centered on the WIPP Site.

People had been drilling through the Delaware Mountain Group for decades without realizing that oil could be produced economically. Log analyses and formation testing showed high amounts of water. Operators thought that these formations would produce mostly water and very little oil. With the advent of modern electric log analyses, it became apparent that oil could be economically produced. Oil discoveries were made, mostly in abandoned deep gas wells. As discoveries were made, a flurry of activity followed as the pools were developed.

The following example shows the methodology for estimating the per well resources. Production is obtained from the Brushy Canyon, the lowest formation in the Delaware Mountain Group. The sandstone is primarily interbedded with shales. The production is from stratigraphic traps. The production in the Delaware is oil and associated gas. Reservoir depths near the WIPP are 7,000 to 8,200 feet. Spacing is on forty acres, in other words, one well per forty acres. Production is from deep basin clastics and submarine fans. In order to project

production away from where it presently exists and in order to project into the undrilled areas, we need a geologic model.

The depositional models for the Delaware sands are deep marine sandstones deposited on submarine fans. Closest to the shelf area, in the northern most parts of the Delaware Basin, the sands were deposited in channels. So they are channel like environments. As you get into more distal areas, the sands become unchannelized and become more laterally continuous.

The Livingston Ridge Pool and Lost Tank Pool are administratively separated. But for geologic and engineering purposes, they form the same pool. Figure 2.2-5 shows an isopach map of the main pay at the Livingston Ridge/Lost Tank Pools. The main pay forms a nice channel going from zero feet to a maximum of eighty feet or so in the middle of the channel. The east west cross section of the main pay shows that in the center the pool is fairly thick. It pinches out on the eastern edge. A north-south cross section shows almost constant thickness throughout the pool in that direction. Hence, the variation is

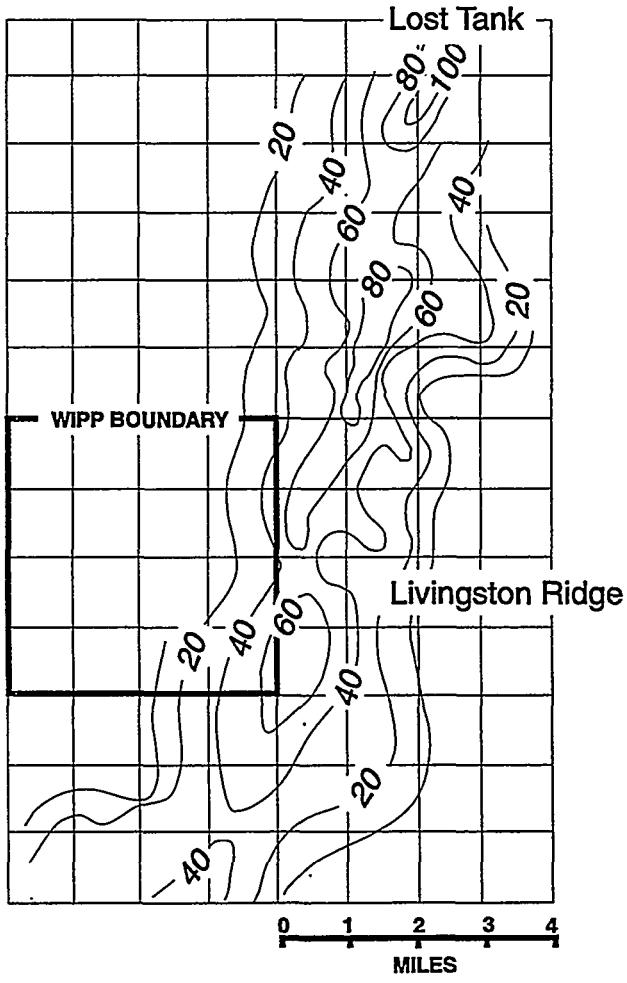


Figure 2.2-5. Isopach of gross channel thickness of Livingston Ridge main pay zone.

in the east-west direction. Economic production takes place where there is forty feet or more of main pay. From this, one can project into undrilled areas[1].

The question then is, are these pools entirely stratigraphic? Most of them seem to be primarily controlled by stratigraphy. The structure map shows that the dip is from the southeast (see Figure 25 of Broadhead et al. 1995). Projecting this channel shows that the WIPP Land Withdrawal Area is either at equal elevation or updip from the present production. Basically, the isopach map and the structural map can be superimposed to determine the areas of probable resources from the projections of known pools.

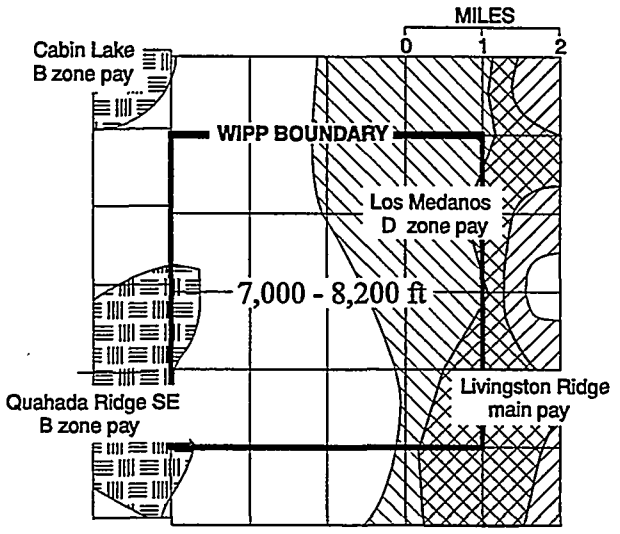


Figure 2.2-6. Areas of known and probable oil and gas resources for Delaware pools.

In Figure 2.2-6, the shaded area along the eastern edge of the WIPP Site shows the projection of the Livingston Ridge Pool. Also shown are other productive pools within the Delaware Mountain Group.

How much oil is each of these forty acre drilling or spacing units going to produce? In the case of the Lost Tank Delaware, a plot of production shows a production decline from roughly 3,500 barrels per month, down after thirty six

[1]Not shown in this report are the control wells and cross sectional diagrams as presented by Broadhead. See Figures 19, 20, and 24 of Broadhead et al., 1995 for the location of the control wells and the cross sectional diagrams.

months, to roughly 1,000 barrels per month. For an exponential curve, there is a high correlation coefficient of 0.87 for this particular well (see Figure 5 of Broadhead et al. 1995).

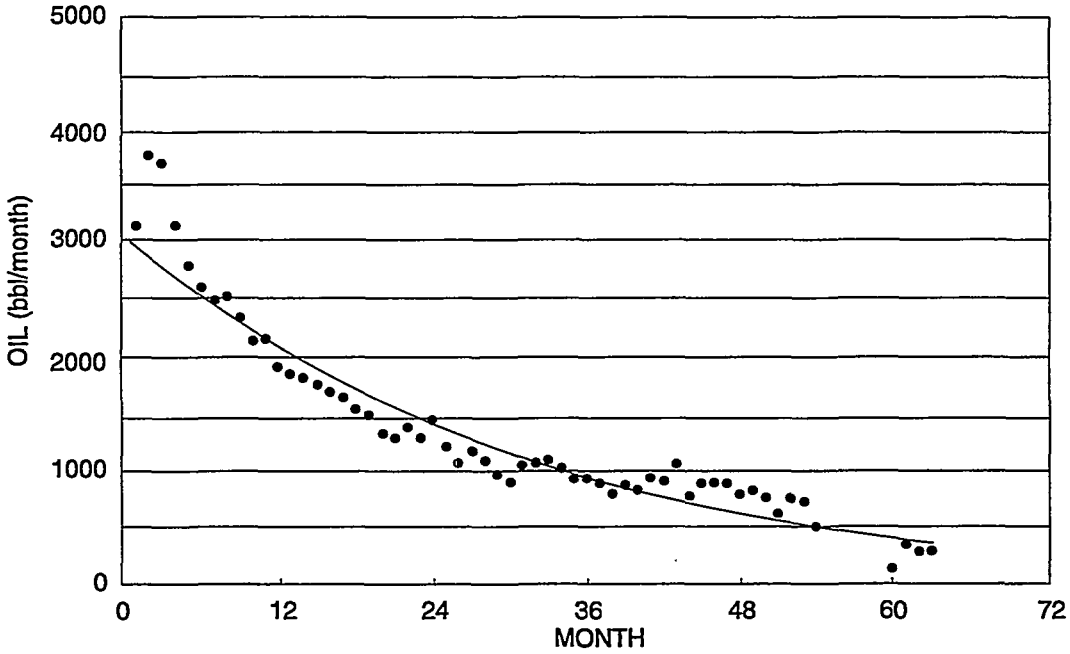


Figure 2.2-7. Average oil production decline curve for Livingston Ridge - Lost Tank Delaware pools, main pay.

As shown in Figure 2.2-7, an average production decline curve was constructed for the Livingston Ridge - Lost Tank pool. Integration of the area underneath that curve yields the resources for an average individual well. In the case of Livingston Ridge, for an assumed economic cutoff of 150 barrels per month, the average well will produce about 89,000 barrels of oil and about 116 million cubic feet of gas. The potentially productive area (calculated in spacing units) is multiplied by the resources for the average well to get an estimate of production for that pool. This was done for each of the Delaware Pools and each of the deeper pools in the area.

Figure 2.2-8 shows an isopach of one of the deep Livingston Ridge zones, the D zone, which produces to the south and the west. The isopach map shows a difference from the Livingston Ridge pay zone and an absence of discrete channels. The result is a blanket type deposit with unchannelized flows containing local thicks and thins and maximums of up to 120 to 140 feet of sand. It never pinches out to zero within the map area.

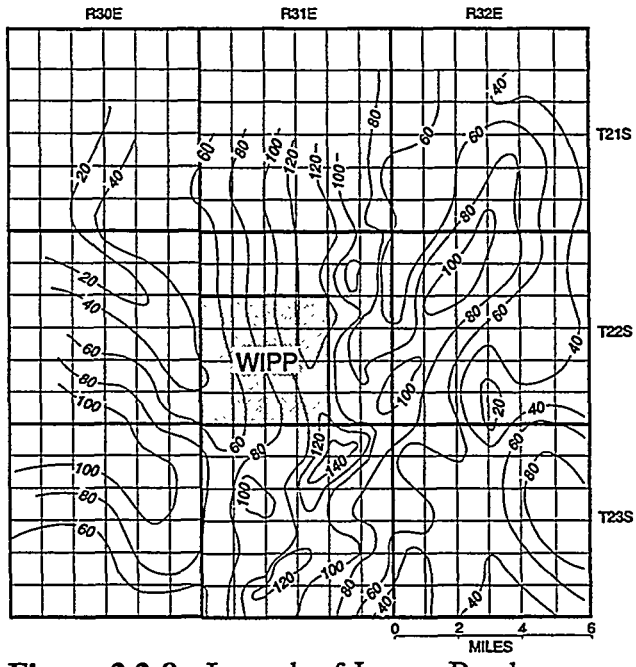


Figure 2.2-8. Isopach of Lower Brushy Canyon Formation zone D.

The deeper sandstones of the 3rd Bone Spring sand produce from stratigraphic or combination traps of deep basin turbidite reservoirs just outside the southwestern boundary of the WIPP Site. Production is oil and associated gas from about 11,000 feet. There are four forty-acre units for probable resources within the WIPP.

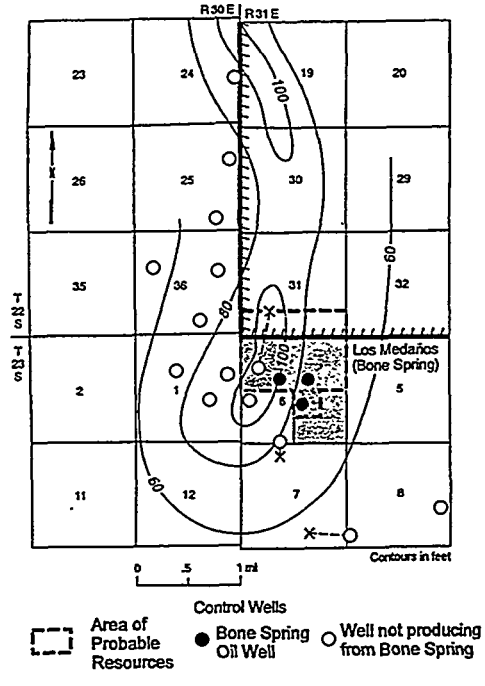


Figure 2.2-9. Isopach of Los Medanos Bone Spring Pool.

For the deeper Strawn Group, production is from limestones interbedded with shales. The reservoirs are bioherms developed on paleogeographic highs. Traps are stratigraphic. Production is gas and liquid condensate at the surface. Reservoir depths are 12,100 to 13,600 feet near the WIPP Site. Spacing is on 320 acres. There are two wells per section. Known and probable resources lie in the northwestern area of the WIPP Land Withdrawal Area.

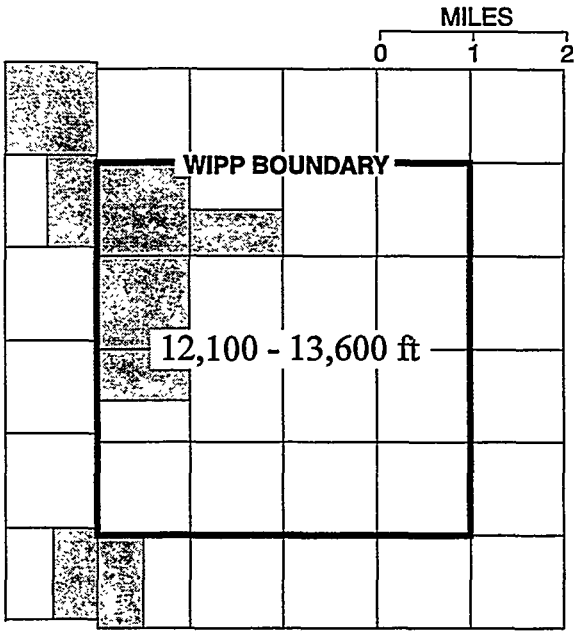


Figure 2.2-10. Areas of known and probable oil and gas resources for Strawn pools projected to extend under WIPP site.

Production of gas and condensate from the Atoka is from sandstones interbedded with shales and limestones. Production is from sandstone channels and a stratigraphic trap near the WIPP. Reservoir depths range from 12,400 to 13,800 feet near WIPP. Well spacing is 320 acres. There are two channels of probable resources that are extensions of existing known discovered traps

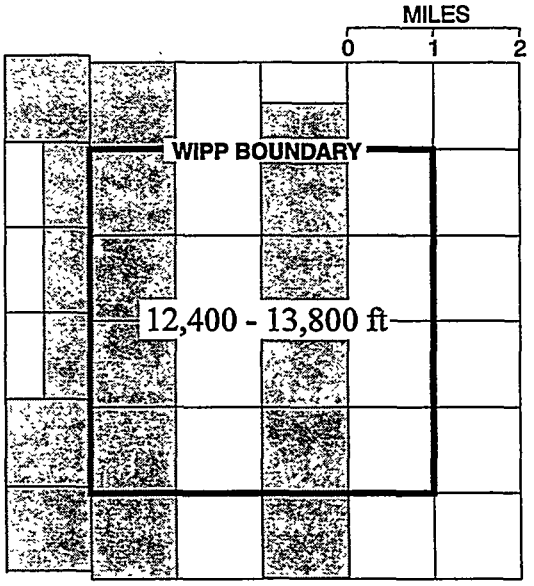


Figure 2.2-11. Areas of known and probable oil and gas resources for Atoka pools projected to extend under the WIPP site.

or pools. There are many sands in the Atoka that are untapped. At this stage of development, it is uncertain whether they are going to be productive or not. The Atoka is the main gas producing zone near WIPP.

The Morrow Group provides the deepest production in the area. Production is from the sandstones of the lower Morrow, interbedded with shales. A whole complex of different geologic models was used to predict production. It produces from stratigraphic, structural, and diagenetic traps. Production is gas and gas condensate. Reservoir depths are 14,300 to 14,800 feet near WIPP. As with the other producing gas zones such as the Atoka and the Strawn, spacing is on 320 acres. Shown are the areas of known and probable oil and gas resources. There is some established production to the south of the WIPP Site. There is no established Morrow production under the Land Withdrawal Area.

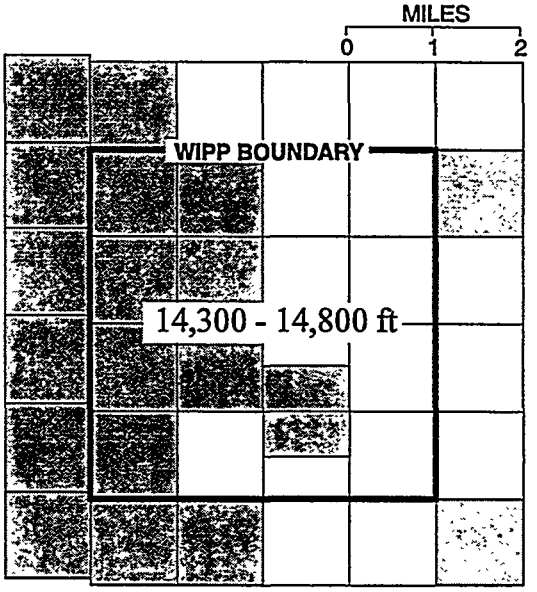


Figure 2.2-12. Areas of known and probable oil and gas resources for Morrow pools projected to extend under the WIPP site.

Table 2.2-1. Probable Resources.

	WIPP LWA	Additional Study Area
Oil and Condensate Primary Recovery (million bbls)	12.3	22.9
Oil Waterflood Recovery (million bbls)	6.4	13.8
Natural Gas (billion ft^3)	186	168

Table 2.2-1 summarizes the probable resources within the WIPP Land Withdrawal Area and the probable resources in the additional one mile wide study area. Under the WIPP Land Withdrawal Area, resources recoverable by primary production are 12.3 million barrels of oil and 186 billion cubic feet of gas. Within the additional one-mile wide study area, resources recoverable by primary production are 22.9 million barrels of oil and 168 billion cubic feet of natural gas.

2.2.2.4 Secondary Recovery Potential

If people decide to waterflood, what could they get if anything? Is it technically possible to waterflood the oil reservoirs, which would be primarily the Delaware under the WIPP Site?

First we looked at the feasibility of waterflooding. Is waterflooding the Delaware technically feasible? Yes, it does appear to be technically feasible although the pools that are under WIPP have not yet been waterflooded. Yes, water has been injected into eight Delaware Pools in southeast New Mexico for secondary recovery. Waterfloods have recently begun in the Avalon and Parkway Pools in the Delaware. One of those is in the Brushy Canyon. If we take a look at the Cabin Lake Pool which produces from the Delaware near the northwestern boundary of the WIPP, there has been some water injection for pressure maintenance purposes and it has showed some good response. There seems to be a chance for technical feasibility for waterflooding.

Feasibility also depends on economics. Obviously, revenues must exceed expenditures. Profits must meet or exceed expected profits from other possible ventures that a company could get into including waterflooding other fields and pools and drilling for primary recovery elsewhere. So even if something is technically feasible, it may not be economically feasible. Our studies show that waterflooding probably is economically feasible. But even if it is economically feasible, it may not be done because there could be a better return on an investment elsewhere.

Within the limited time available, we analyzed two mature waterfloods within the Delaware Mountain Group in southeast New Mexico. We used historical production data to estimate ultimate recovery from each of those mature waterfloods.

One of the mature floods examined was the Paduca Delaware Field. Primary production started in 1961. Projection of the exponential decline curves showed an estimated recovery of 8-1/2 million barrels of oil by primary production and 5-1/4 million barrels by secondary recovery. In the case of Paduca, there was a 61% increase in production by waterflooding the reservoir. Projecting primary and secondary recovery for the Indian Draw (Delaware) Field yields an 81% increase in production by waterflooding. Worthington made an industry estimate of a 100% increase in recovery from Brushy Canyon by waterflooding the East Shugart Delaware field, which has not been waterflooded at this time.

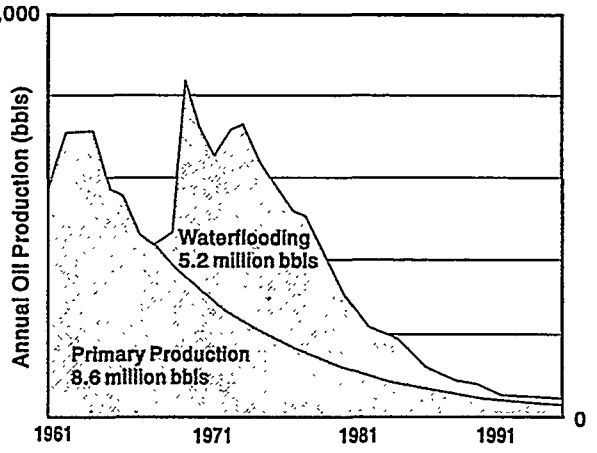


Figure 2.2-13. Production from Paduca Field.

None of the reservoirs under the WIPP Site have been waterflooded yet. Given the three estimates of 61%, 81%, and 100% additional oil recovery by waterflooding, the Bureau used a conservative estimate of 60% additional recovery by waterflooding to project recovery by waterflooding reservoirs in the vicinity of the WIPP Site. Further, there was proprietary information from the oil companies operating in the area indicating that they anticipated 70% to 80% increase in production by waterflooding the Brushy Canyon Formation. To accommodate the uncertainty, the Bureau used a very conservative estimate.

Production from the Cabin Lake Delaware Pool, just outside the northwestern corner of the WIPP Site, was used to provide technical information on the feasibility of waterflooding. Phillips Petroleum is the primary operator of this pool. Figure 2.2-14 shows the initial production at about 4,000 barrels per month for this well and a gradual production decline. The operator completed two wells nearby for pressure maintenance, which is a very early-stage form of waterflooding. The immediate response to water injection is clearly shown. The Delaware sands in the vicinity of the WIPP seem to be amenable to waterflooding. It doesn't mean someone is going to waterflood, it just means that the fields are amenable to waterflooding.

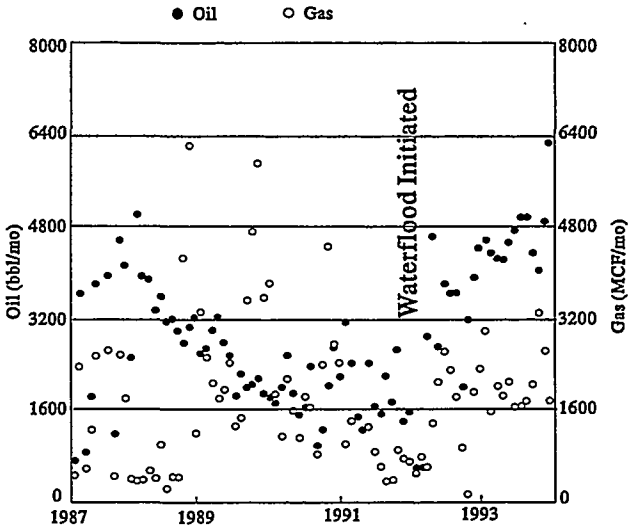


Figure 2.2-14. Monthly production of oil and gas, Phillips Petroleum Company No. 2 James A well, Cabin Lake Delaware pool.

2.2.2.5 Summary

In the Delaware Mountain Group, there is approximately 10 million barrels of oil recoverable by primary production and another 7 million barrels recoverable by secondary recovery. A very conservative estimate shows a little oil recoverable from the Bone Springs Formation and some condensates recoverable from the Strawn, Atoka, and Morrow Formations.

As to gas resources within the WIPP Land Withdrawal Area, approximately 125 billion cubic feet of gas is recoverable from the Atoka Formation, about 30 bcf non-associated gas from the Morrow Formation, and about 20 bcf associated gas

from the Delaware Mountain Group. The Strawn Formation and the Bone Spring Formation would also produce gas.

The above estimates are limited to probable resources. There are probably undiscovered resources under the WIPP Site. But the area has not been drilled. Until then, there is no way of knowing for certain the extent of such resources. For years, operators drilled through the Delaware without knowing of the presence of economically recoverable oil in those formations.

2.2.2.6 Questions:

Wendell Weart: I was wondering if you could provide an average number for the lifetime of a well in this area of the basin, and an average pool lifetime.

Ron Broadhead: Lifetime of the wells. Even though there are some differences from well to well and pool to pool, we can use the average well from the Livingston Ridge to give some idea of a well lifetime. From initial production until about 150 barrels per month, this well is going to produce about 92 months of primary recovery. It is less than ten years for an average Delaware well. Probably production in Delaware pools is going to be in the ten year range, maybe less, because these pools tend to be drilled out and developed very quickly.

Chuck Byrum: What if you add secondary recovery to that? How much would that extend the field life?

Ron Broadhead: Secondary recovery will extend the field life. Secondary recovery will have to start while the primary well is producing. If you wait until the wells are plugged out, secondary recovery is not going to be economically feasible. Secondary recovery is going to have to start when production is around fifty percent, maybe as low as thirty percent of the peak primary production. There are ten years, at the most of secondary recovery, probably less.

Peter Swift: You described the pay zones as about forty feet thick for each pool. Is that all oil saturated or is that just the sand thickness you need in order to have a productive oil zone?

Ron Broadhead: For economic production from Livingston Ridge at present, you need at least forty feet.

Peter Swift: Forty feet of oil or forty feet of sand?

Ron Broadhead: Forty feet of pay, of channel. There is actually less sand. If you get less than forty feet you are going to require a multiple completion. There are a few wells that are completed in multiple zones.

Peter Swift: Is there an oil water contact in that forty feet?

Ron Broadhead: No, there is not.

Chuck Byrum: How much water is being produced during primary recovery per well on average and how much during secondary recovery? Is there a difference?

Ron Broadhead: I don't have an exact number. I can't recall exactly what the water production is from primary. But these wells in the Delaware produce a very high water cut.

Chuck Byrum: Some of the numbers that I have seen, it is like a four to one ratio.

Ron Broadhead: Yes, the water cut is very high. These are fairly unconventional sands. They are pretty fine grained. There is a high water saturation. There is a lot of moveable oil and moveable water. It is not being driven by an oil-water contact. It is water in the actual pore space with the moveable oil.

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2.3 Observations of Water Level Rises in the Culebra Aquifer

2.3.1 Presentation by Rick Beauheim (no synopsis)

The purpose of the presentation was to summarize the observed water level rises since 1988 and offer thoughts on explaining the water level rises, starting with the wells to the south and working northward. The plots start at 1988 because it was in 1988 that water level rises were first noticed in well H-9.

Shown at right are the locations of the Culebra Dolomite Wells in the vicinity of the WIPP Site. Well H-9 is approximately six miles to the south of the WIPP Site. In 1988, a rise in the water levels was first noticed at well H-9. The water level rise propagated north to other wells.

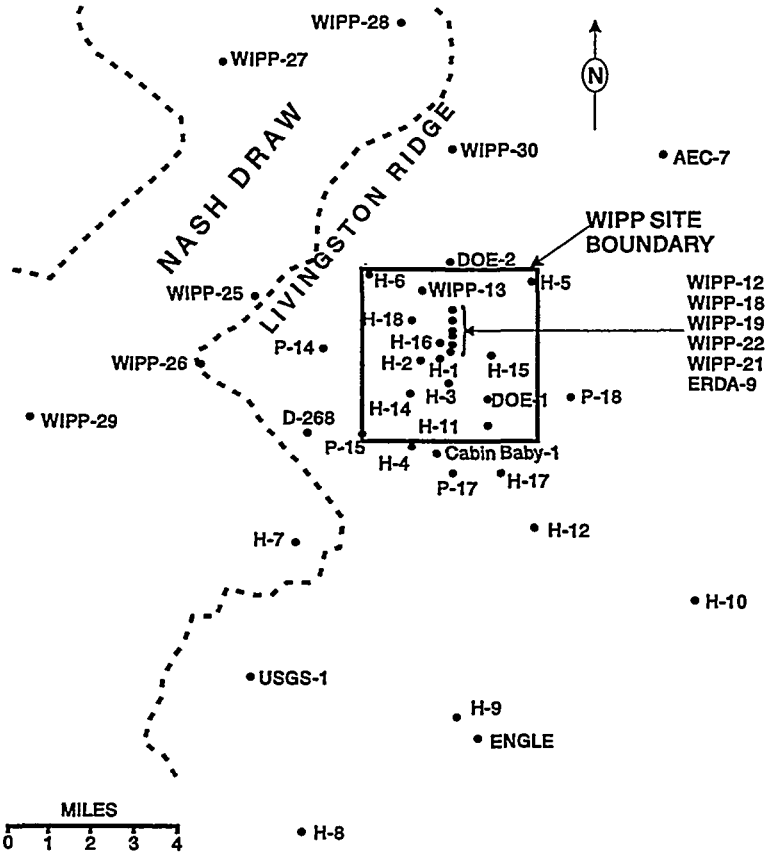


Figure 2.3-1. Locations of Culebra Dolomite Wells in the vicinity of the WIPP Site.

Since that time there have been other Culebra water rises related to other phenomena. To explain the other phenomena, the presentation was divided into three regions around the WIPP Site, starting with each well to the south, covering each well about the center, and finishing with the wells to the north.

2.3.1.1 Southern Region of the WIPP Site

For at least five years prior to 1988, the water level at H-9 was very stable at 431 to 432 feet below the surface. Between March and April of 1988, the water level took an abrupt turn and kept on climbing. In a natural system, that is a system undisturbed by man, you do not expect to see a steady water system and then in the space of one month, the whole thing turn. That is not a natural kind of phenomena. It screams that some event has occurred. Some human induced event has occurred. The rise generally continued from 1988 until about 1993. In 1993, the water level fell off rather abruptly, has been fluctuating, and is now on another rise. The events at H-9 are the result of some phenomena, most likely some well effect.

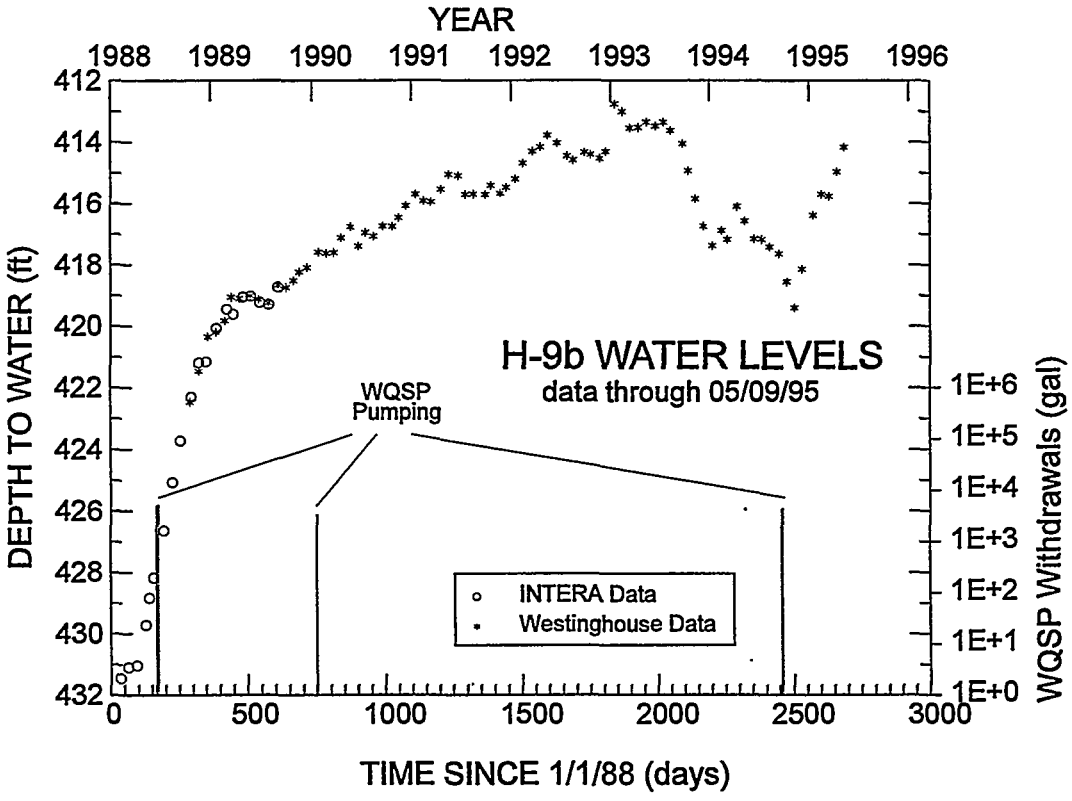


Figure 2.3-2. Well H-9b water levels.

The first well to the north of H-9 is H-12. At the time water levels at H-9 began rising, the water levels at H-12 were controlled by other events. One of those events was the H-11 multipad test. But after the conclusion of the pumping test, the water level was going to clearly recover past the point prior to the pumping test. A water quality sampling test brought the water level down, but at the end of the sampling test the water level continued climbing steadily. The total water level rise at H-12 was on the order of nine feet.

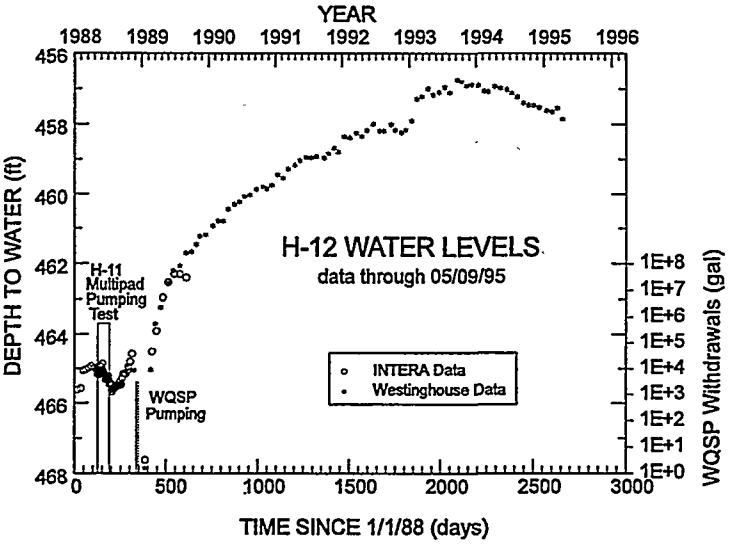


Figure 2.3-3. Well H-12 water levels.

Well H-17 lies a little further to the north of well H-12. Again, after the response to the H-11 multiwell drawdown test, the recovery continued to climb. The water level has fairly well stabilized at the upper end. From 1993, there is not the same kind of detail that is seen in some of the other wells.

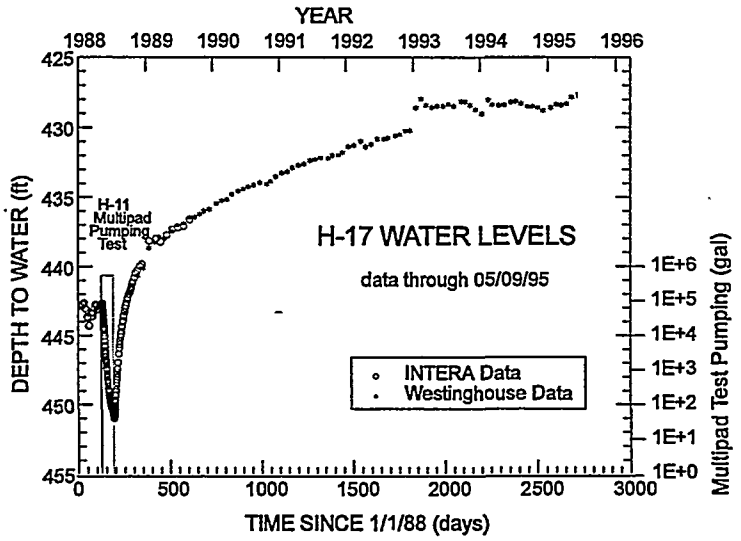


Figure 2.3-4. Well H-17 water levels.

Well P-17, which is due west of H-17, shows the same kind of behavior but it does seem to be a little more in touch with the other fluctuations that have occurred since 1993. There was, again, on the order of nine feet of water level rise.

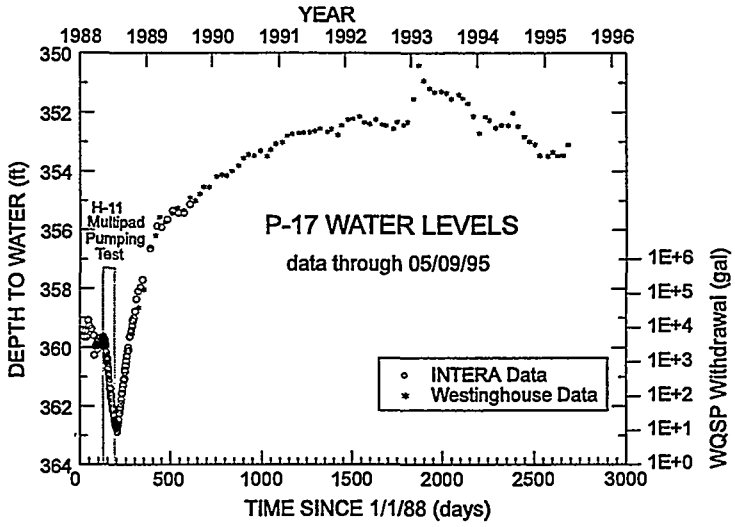


Figure 2.3-5. Well P-17 water levels.

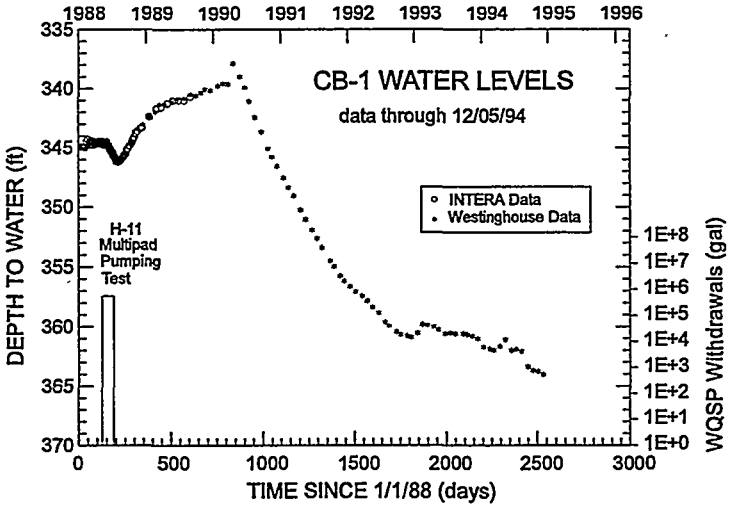


Figure 2.3-6. Well CB-1 water levels.

Cabin Baby [CB-1], which is just to the northwest of P-17, saw the H-11 multipad test response. The water level was continuing to rise and then the packers and bridge plug failed. That drawdown response (after early 1991) has nothing to do with the Culebra. At that time, the Culebra and everything else in that well were interconnected. Late last year we replaced the packers in that well and put in a new bridge at the base of the casing. Westinghouse may not be aware of that and needs to go back to measuring the water levels.

Well H-4b is the next well slightly to the northwest of Cabin Baby, and again you see the same response to the H-11 well and then this rise. Westinghouse takes water samples from time to time resulting in an occasional drawdown, but the well does recover. But they also went into H-4b and a number of other wells. Some of these older wells were caving in and were not providing full access to the Culebra Formation. Some of these wells were cleaned out. The cleaning required Culebra water, but Culebra water was not available from well H-4b. Water from well H-3 was used for all of these 1992 cleaning exercises. The water from H-3 has a different density from the density of the water in the wells that were cleaned out. As a result, upon completion of the cleaning exercise the water level had declined. The foreign water was pumped out and the water level rose sharply as a result of density change more than anything else. The water level has continued to decline. The decline in the H-4b well may reflect the decline in the Cabin Baby well because H-4b and Cabin Baby are very close to each other. The Culebra saw a pressure decline in the Cabin Baby well, which would create the drawdown in well H-4.

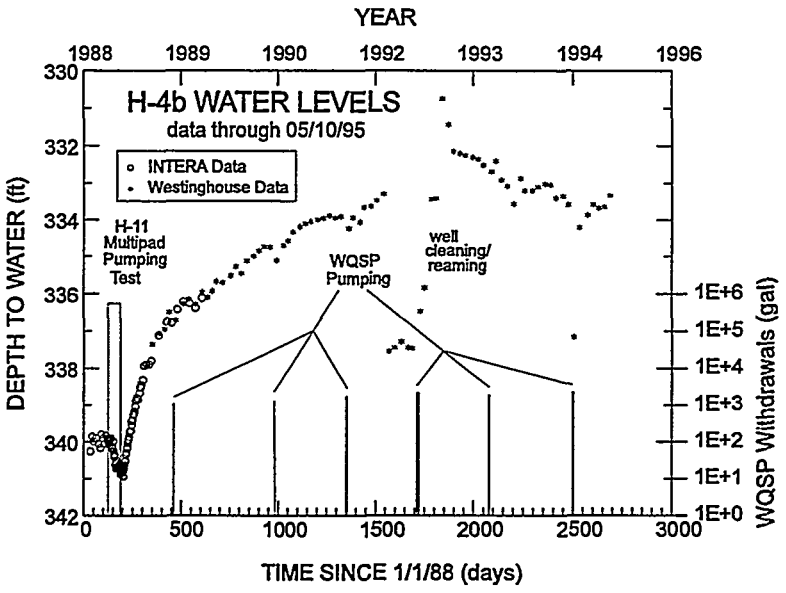


Figure 2.3-7. Well H-4b water levels.

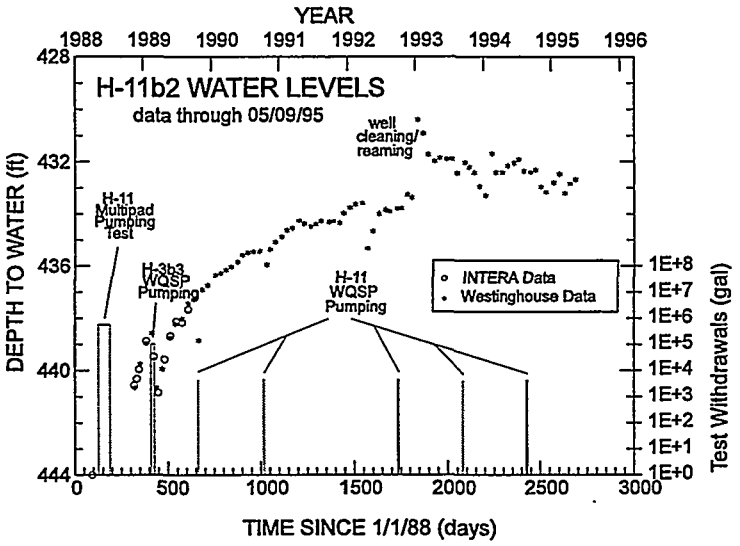


Figure 2.3-8. Well H-11b2 water levels.

After the H-11b2 multipad pumping test, there was pumping at H-3 that effected the water levels at H-11. After the recovery from the H-3 pumping test, the water level continued to rise. The plot shows the response to the cleaning exercise. The water level rose with the density change. The water level has continued to rise since then (with the rest of the response very similar to that at H-4b).

Well P-15 shows the same type of response (as H-11b2).

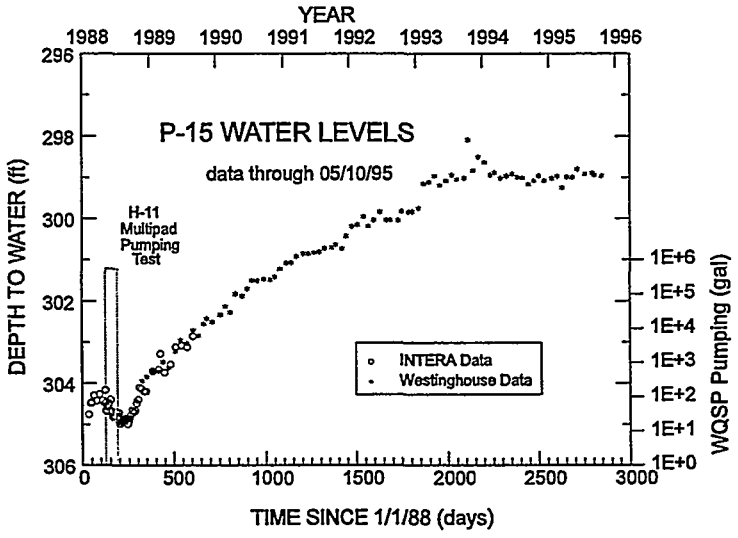


Figure 2.3-9. Well P-15 water levels.

Well H-10 lies northeast of H-9. Well H-10 has quite low transmissivity. It is a very tight well. It appears that whatever happened at H-9 or in the vicinity of H-9 took a number of years to propagate over to H-10 because of the low permeability. It wasn't until the end of 1990 and beginning of 1991 that the water level in H-10 began to take off. The water level has definitely climbed about three feet in the last three or four years.

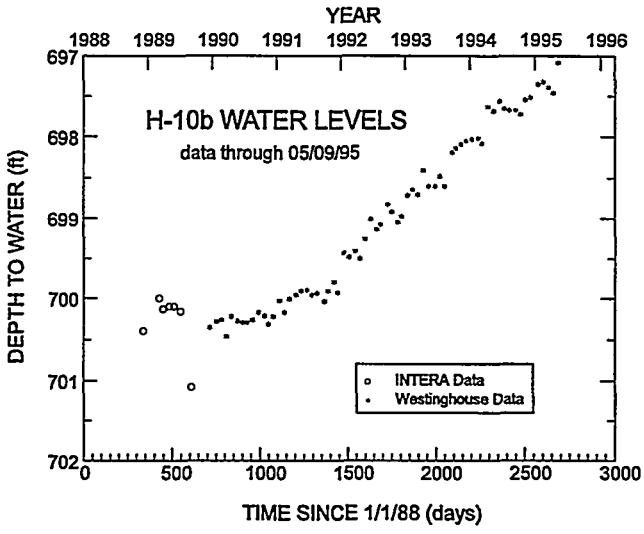


Figure 2.3-10. Well H-10 water levels.

Well H-7 lies off to the west in an extremely high permeability region. H-7 may also be under water table conditions. . The scale in the water level plot is on the order of three feet. What appear to be large amplitude fluctuations are actually less than a foot in water level change. Most of these changes are probably due to barometric effects, earth tides, or something of that nature. The changes are just a fraction of a foot. But, one gets the sense that, for

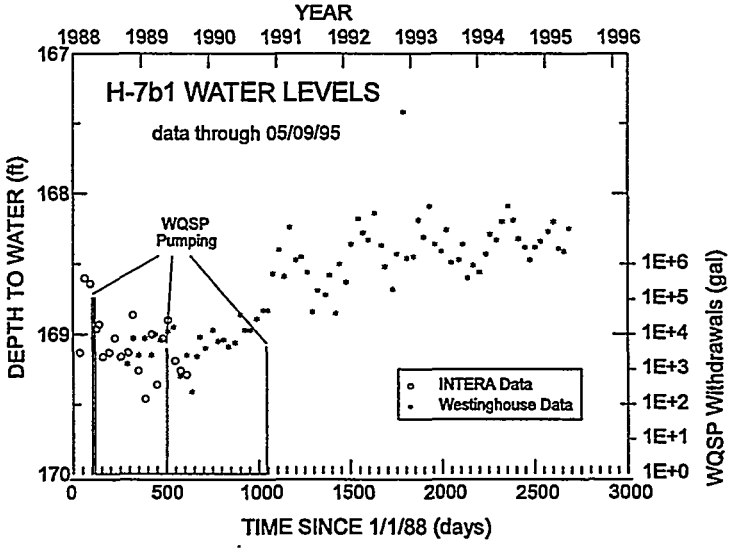


Figure 2.3-11. Well H-7 water levels.

years, the water level seems to be stable at about 169 feet. One does get a sense that the water level is climbing a bit at H-7.

So what might be going on? In 1990, Marsh LaVenue looked at all these rising water levels to the south and went out looking for injection wells in the vicinity of H-9 that might be a cause of this kind of a water level rise. He identified a number of injection wells, some of which the operators thought might be leaking. We really had no evidence that the leakage was specifically going into the Culebra. We were mainly interested in figuring out if that type of a hypothesis, that is a leaking injection well somewhere in the vicinity of H-9, could cause the types of water level rises that we have observed.

LaVenue identified one well not too far from H-9 that was injecting about 12 gallons per minute into a deeper formation. So we decided to play a "what if" game. What if some of the water being injected into this well is actually leaking into the Culebra? Using the existing regional groundwater flow model, LaVenue simulated injection at that well location. LaVenue found that if he put the full 12 gpm, into the Culebra, at that location, he could very nearly match the observed water level rises. Now that is in no way, shape, or form, proof that that [salt water disposal] well is the cause of these water level rises. It merely shows that if something is being injected into the Culebra, in that region, and at about 12 gallons per minute, you can get this kind of a response. It confirms our hypothesis that it really does take some kind of discrete event, turning on a pump, turning on injection, something changing to cause these kinds of water level responses.

From my standpoint, it's really not important what well might be responsible for this. It could be any well out there. The point is, in the future, we won't know. In a hundred years from now we won't know what wells might be leaking. We won't know what casing has failed, what cement jobs have gone bad. The point

is simply that other units can be connected to the Culebra. They can cause changes in the water levels.

So what is the overall implications with respect to compliance? Well, in this particular instance, this well is to the south of the WIPP Site. Rising water levels to the south, that propagate to the north, as they propagate, they diminish in magnitude. What this in effect does, in this instance, is decrease the gradients, the natural gradients, within the Culebra, which are from north to south. So, under ordinary conditions, you have a particular gradient which in the event of a breach of the repository, would drive radionuclides to the south under the existing gradient. Well, what this kind of event does, is it decreases that gradient. So this would actually slow things down a bit. I don't think that is significant because I don't expect this to be a particularly long lived kind of response, probably on the order of tens of years, then it will damp out, reach some new equilibrium. Climate changes in the future could cause similar types of gradient changes, so I really don't think it's important. Let's continue to look at the other water levels and I will show you some other things that are going on.

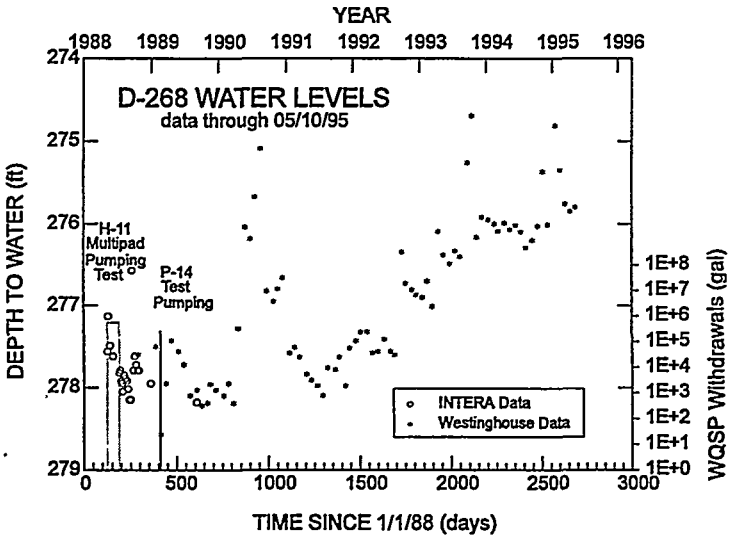


Figure 2.3-12. Well D-268 water levels.

D-268 is off the southwestern corner of the site. We have a troublesome packer in this well. It has to be continually reinflated. It likes to deflate. It sees a lot of water fluctuations as that packer loses its integrity and as

the packer is reinflated and reestablishes its integrity. There may be a slight rise in the water level at D-268.

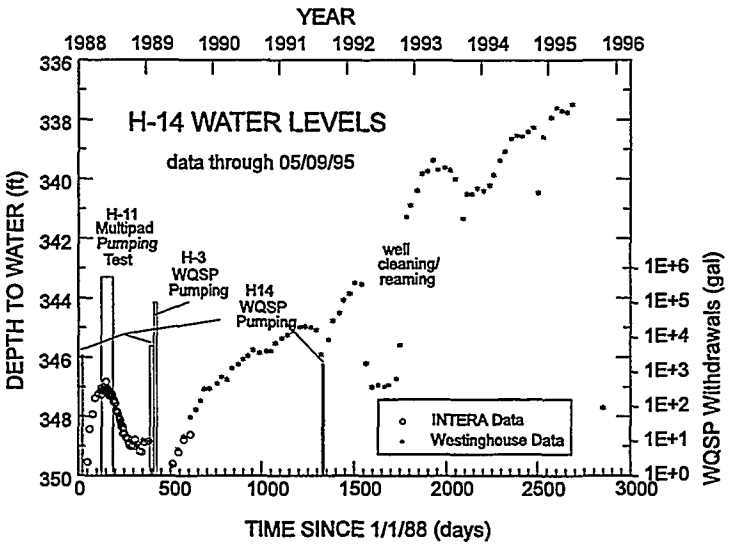


Figure 2.3-13. Well H-14 water levels.

At H-14, there is the same type of response as observed at the other wells - a well cleaning exercise - pumped out - changes in fluid density.

This is a greatly expanded scale, with sixty feet on the vertical scale to capture the response to the H-11 multipad pumping test. The water level continued to rise after the H-11 test. Then there was a packer failure in DOE-1. That packer has since been replaced and the water level is starting to recover from that event.

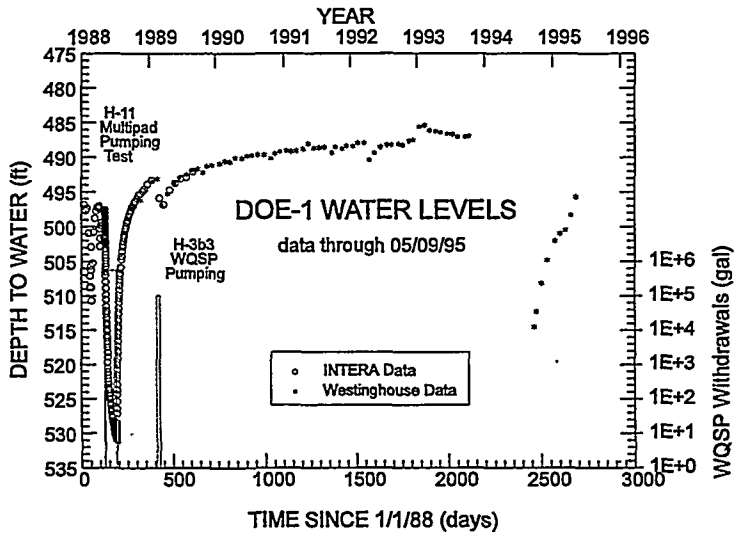


Figure 2.3-14. Well DOE-1 water levels.

Well H-15 shows a type of response similar to that of DOE-1.

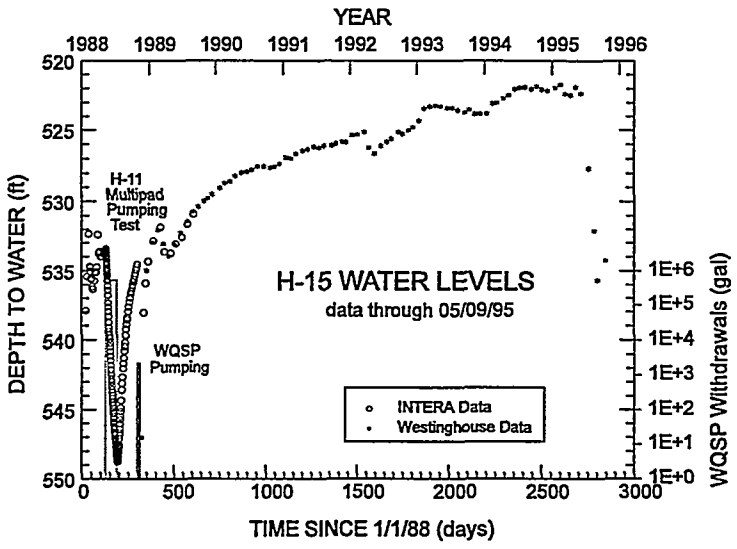


Figure 2.3-15. Well H-15 water levels.

2.3.1.2 Central Region of the WIPP Site

The shafts at WIPP caused a large cone depression in the Culebra. Starting back in 1981, when the exploratory shaft was first drilled, there has been leakage into all the shafts at the WIPP Site and that leakage has brought water levels down, in the Culebra, over the entire site. Over the years, there have been a number of episodes of shaft grouting which have been of varying effectiveness, and sometimes that effectiveness has been limited in time. So, some of the grouting jobs were repeated.

The most recent shaft at WIPP is the air intake shaft. Before the air intake shaft was drilled, we put in an observation well, H-16, fifty feet away to monitor the responses of the Culebra to the construction of the air intake shaft. The pressures that have been measured at H-16 since about August 1987 are shown. The stabilized pressure in the Culebra before the air intake shaft was drilled, was about 128 psig. When the pilot hole for the AIS was drilled, the hole was loaded with drilling mud. Once the drillers hit the Culebra, the pressure at H-16 rose in response to the pressure exerted by the drilling mud. Once the drillers holed through to the underground, the column of drilling mud shot into the underground

resulting in an atmospheric pressure condition in the Culebra. So the pressure in the Culebra at H-16 dropped significantly at H-16. The drillers then upreamed through the Culebra. The pressure again dropped significantly at H-16. The air intact shaft was then lined. The pressure started recovering. Then Fred Gelbard went into the air intake shaft and drilled four horizontal core holes into the Culebra. That caused the pressure to drop at H-16 because of the free drainage into the holes. Those [core holes] were then pressure grouted because the pressure had increased and then the pressure started climbing again. The interesting thing about the pressure grouting is that by simply pressure grouting those four holes, the pressures rise, the buildup was much more than one might have expected. By grouting those holes, the overall leakage into the shaft was greatly reduced.

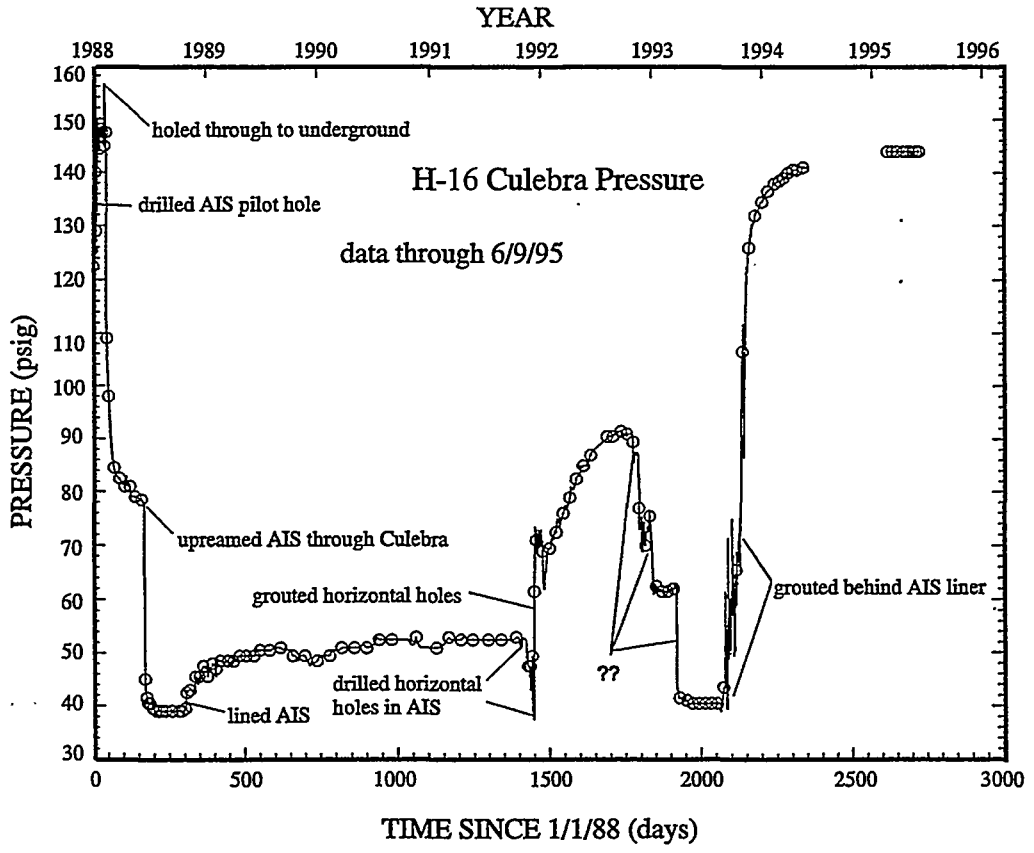


Figure 2.3-16. Well H-16 Culebra Pressures.

There were a number of episodes that I have not been able to pin down. Something happened around the air intake shaft that caused the pressure to drop in at least three distinct steps. I am not quite sure exactly what happened. The pressure stabilized around 40 psig until two summers ago when the project grouted behind the liner. This was a very serious grouting exercise and by far the most effective grouting exercise that has ever been done at WIPP. Sandia was working with the grouting contractor, providing the contractor with pressure data in almost real time. We could show them every single time they drilled a hole into the Culebra to grout. We could see the pressure response at H-16, the immediate drawdown response to drilling that hole. As soon as they did grout that hole, we saw the pressure spike associated with it. So we could track the effectiveness of their grouting program in progress. As soon as the grouting was completed, the pressure at H-16 rose and is now stabilized at 144 psig. Recall that in 1987, the level was stabilized at 128 psig. This grouting job was very effective. The pressure is now higher than it was before the air intake shaft went in. I spent this much time on this well because the other wells exhibit similar behavior. Well H-16 is only fifty feet from the air intake shaft but all of these responses propagated throughout the center of the site. Similar responses are seen for wells ERDA 9, H-1, H-2b2, H-3b2, WIPP-21, WIPP-22, WIPP-18, WIPP-19 and WIPP-12. The responses are more subdued with increased distance from the air intake shaft.

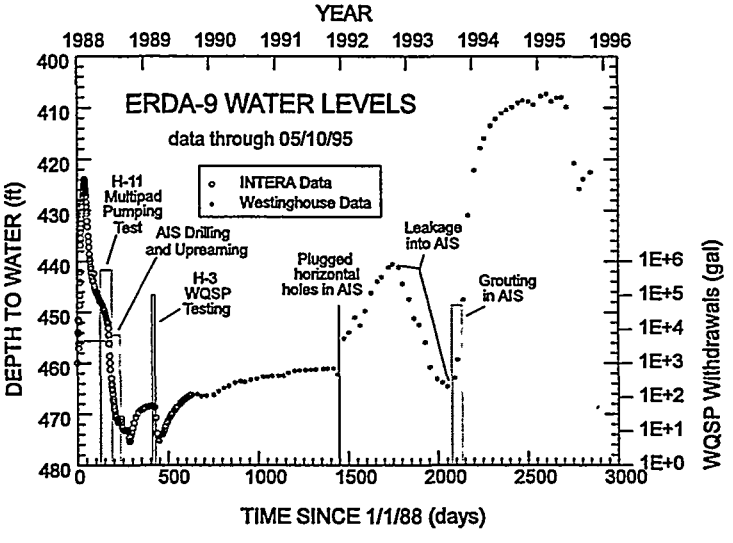


Figure 2.3-17. Well ERDA 9 water levels.

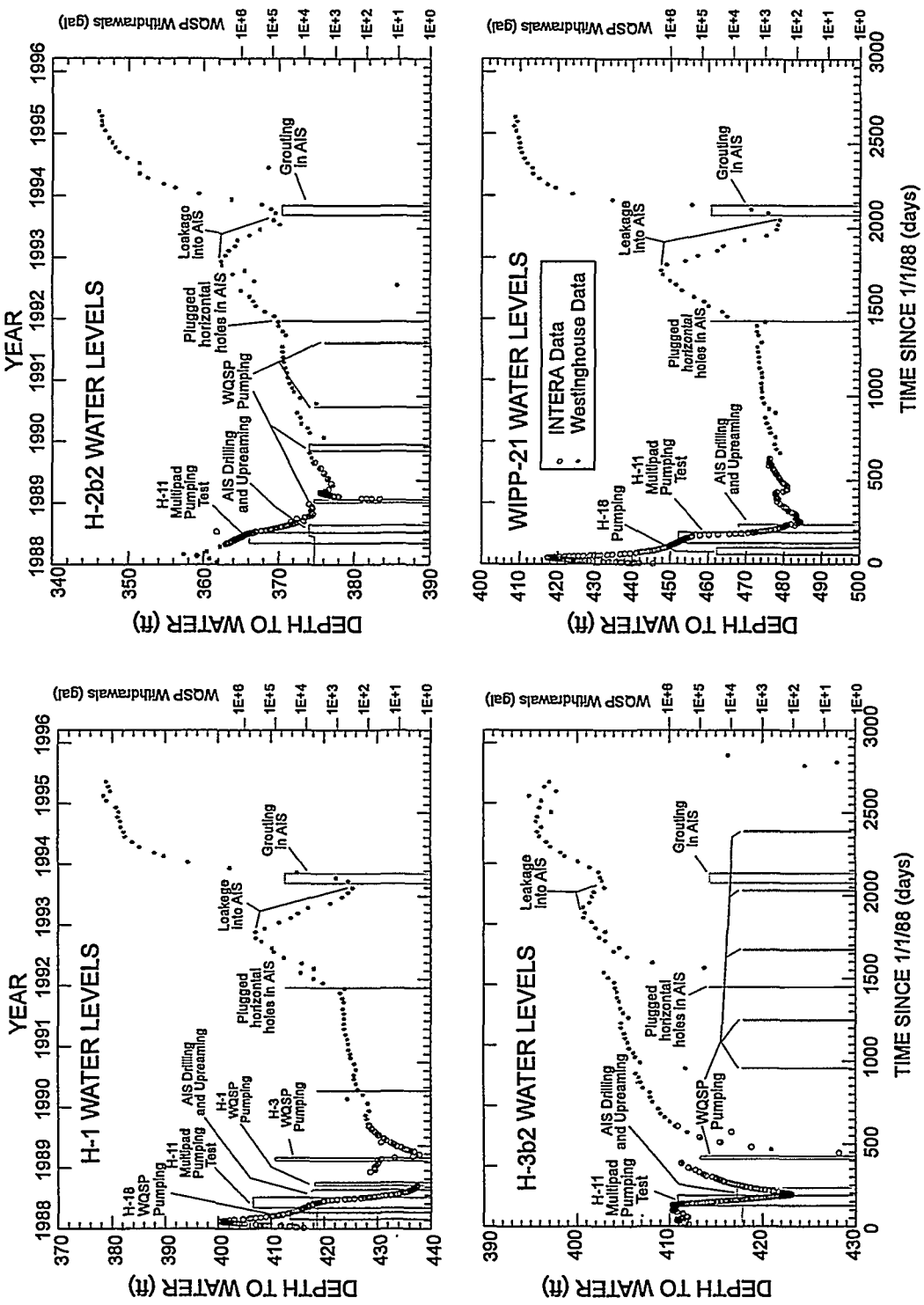


Figure 2.3-18. Wells H-1, H-2b2, H-3b2, and WIPP-21 water levels.

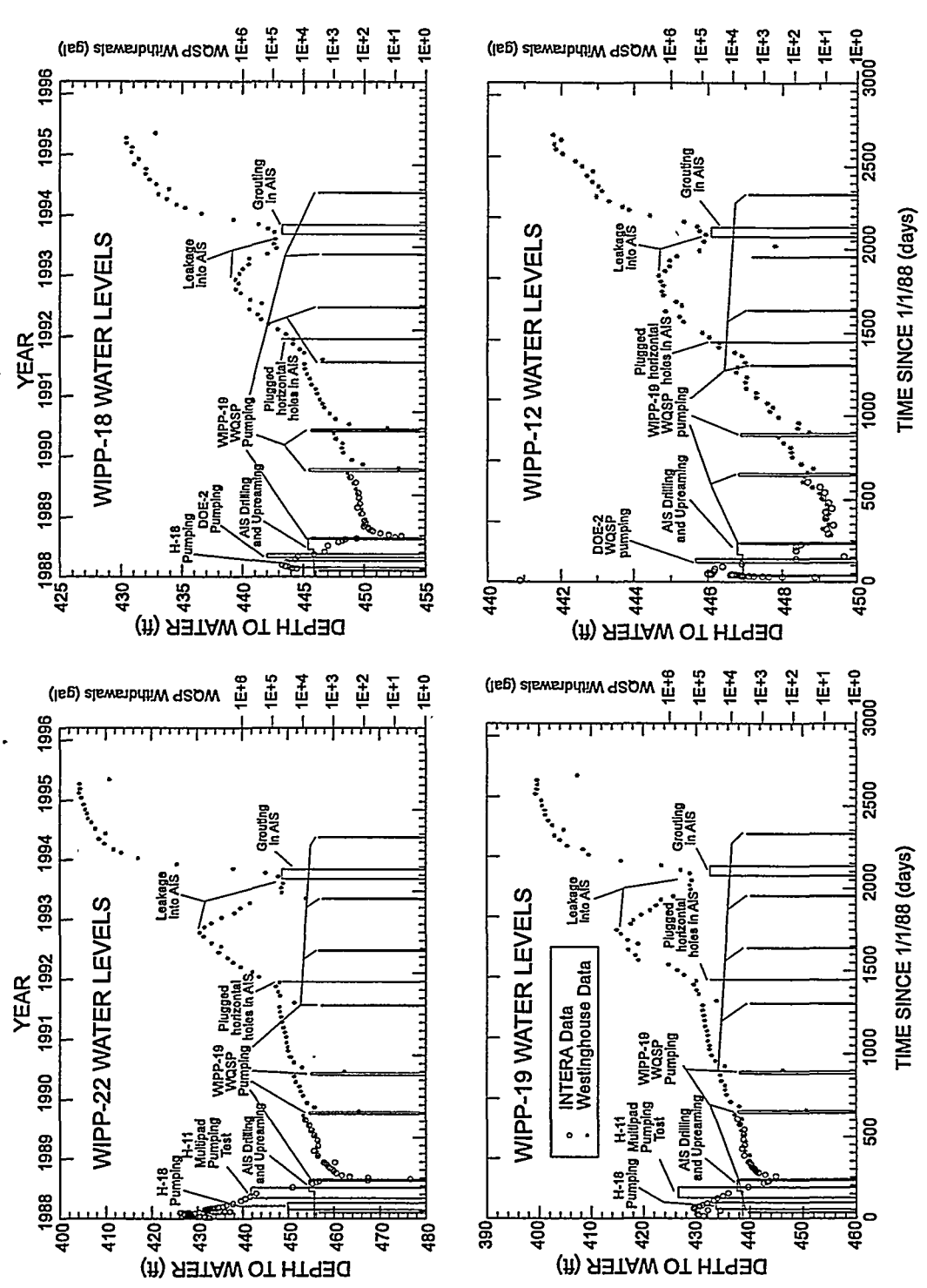


Figure 2.3-19. Wells WIPP-22, WIPP-18, WIPP-19, and WIPP-12 water levels.

Well H-18 shows a general rise in water levels.

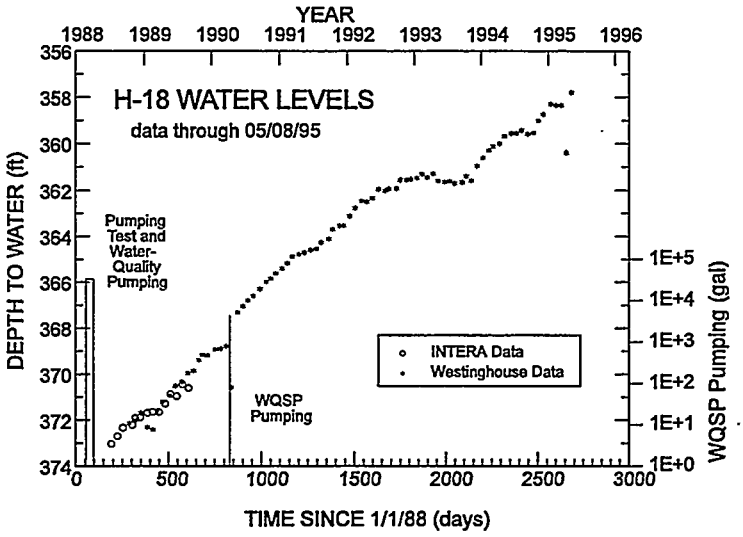


Figure 2.3-20. Well H-18 water levels.

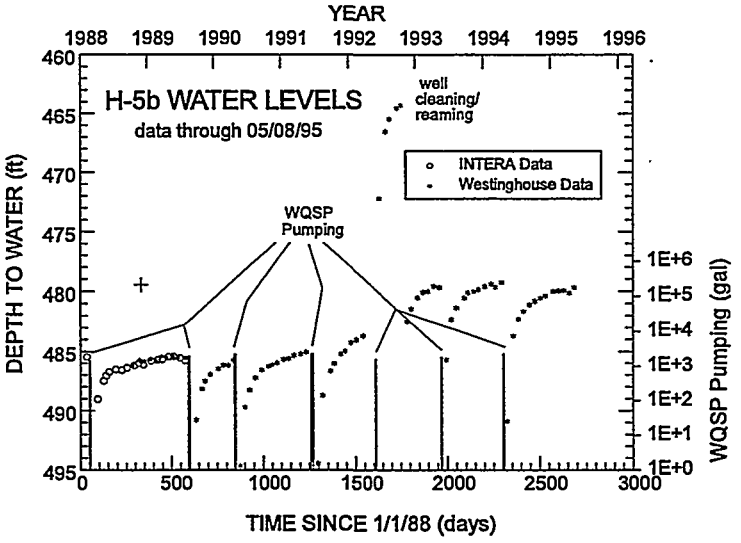


Figure 2.3-21. Well H-5b water levels.

Well H-5b is in the extreme northeast corner of the WIPP Site. It is in a very low permeability zone and it takes a lot to make anything happen at H-5. It is pretty much isolated from other events. It does show that for each water quality sampling, the well takes a time to recover and is still recovering when the next sample is taken. The water level sharply increased, for a while, in response to the well cleaning and reaming. Now the water level is in line with where it should be.

Well DOE-2 shows a water level rise up until mid-1992. Since then the water level has been falling off. This one is pretty anomalous. You don't see this kind

of fall off in any of the surrounding wells. DOE-2 is like DOE-1 and Cabin Baby and some of the other wells. It has a bridge plug in the base of the casing which isolates the Culebra from the Salado and the Castile. There is another deep bridge plug which isolates the Castile from the Bell Canyon. Looking at the water level plot, I would guess that one or both of those bridge plugs have failed and we need to reenter that well and put in a new bridge to isolate the Culebra.

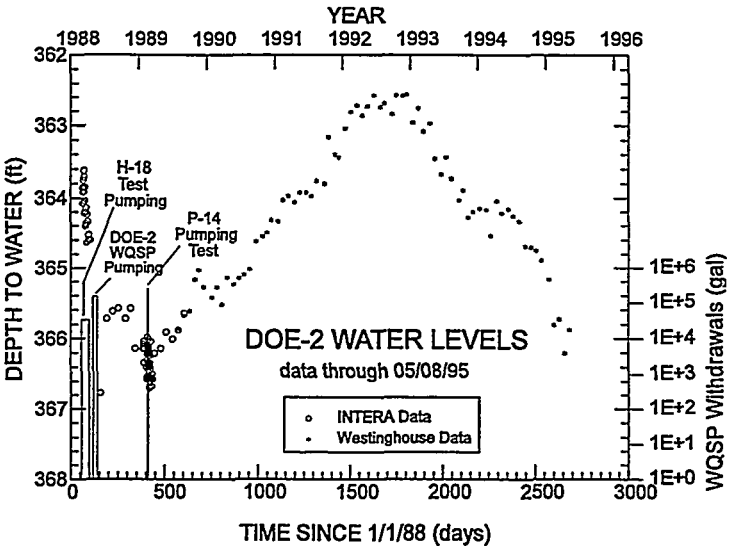


Figure 2.3-22. Well DOE-2 water levels.

WIPP-13 shows a water level rise. As you continue north towards Nash Draw, you see this kind of rise. This rise may be due to a combination of events. The wells are far enough away from the shaft so that they won't see a distinct response to a distinct episode at the air intake shaft. Instead you see a

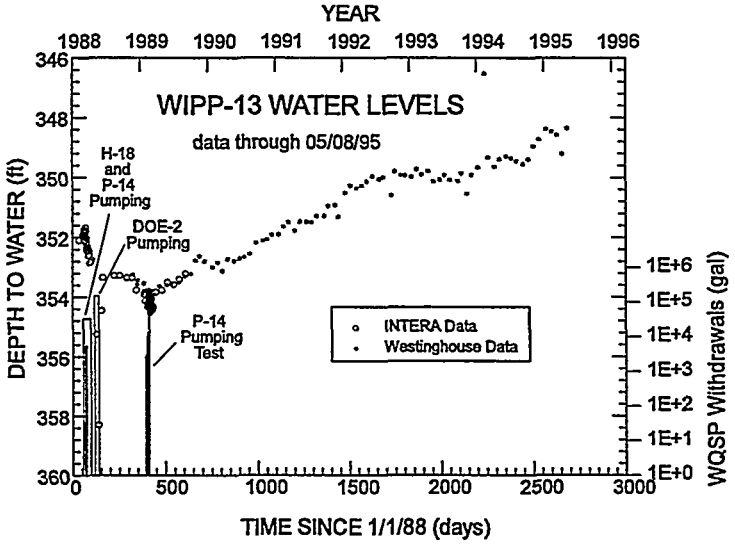


Figure 2.3-23. Well WIPP-13 water levels.

generalized response. In general, leakages into all of the shafts have decreased over the years. The rise in the wells to the north just reflects an overall recovery to the leakage into the WIPP shafts.

H-6 has risen on the order of about 4 or 5 feet since 1989. It is important to remember that H-6 has been there since the late 1970's. Even though it appears that the water level is rising, today's water level does not represent an all time high. Today's water level is approaching the water level of the late 1970's before any of the WIPP shafts were drilled. This appears to be a recovery to the drainage into the WIPP shafts.

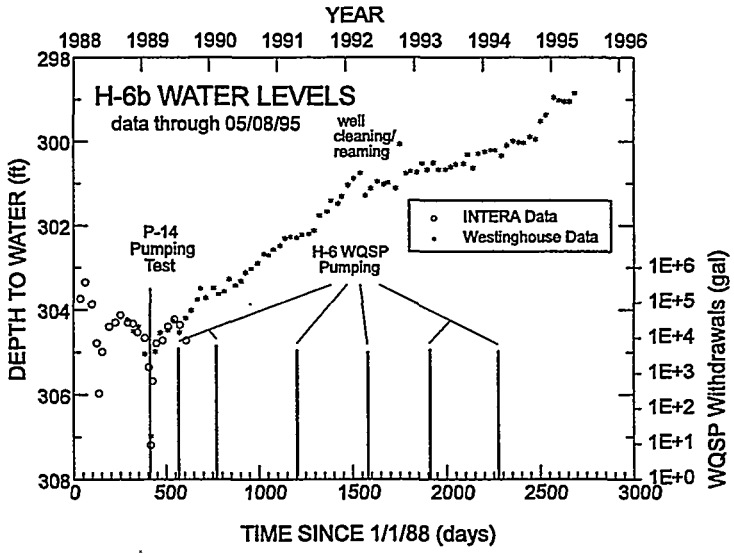


Figure 2.3-24. Well H-6b water levels.

P-14 is in a very high transmissivity region. The water level had been fairly stable. Now it looks like P-14 is going through an historic high.

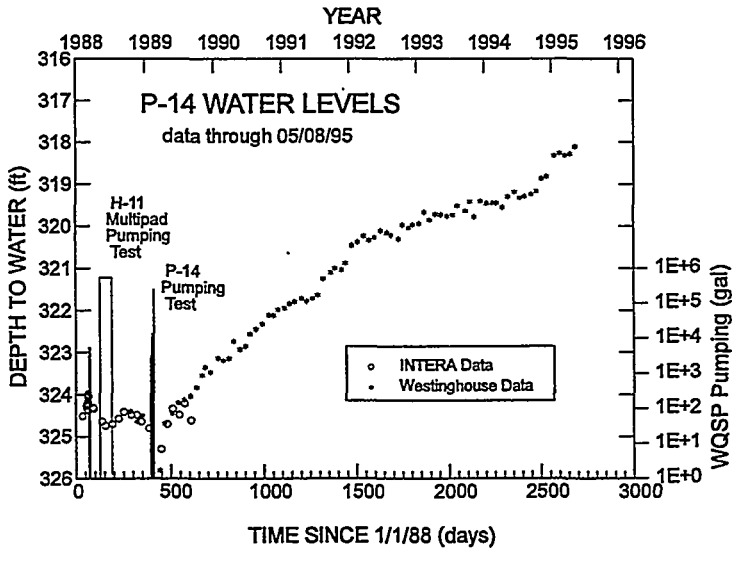
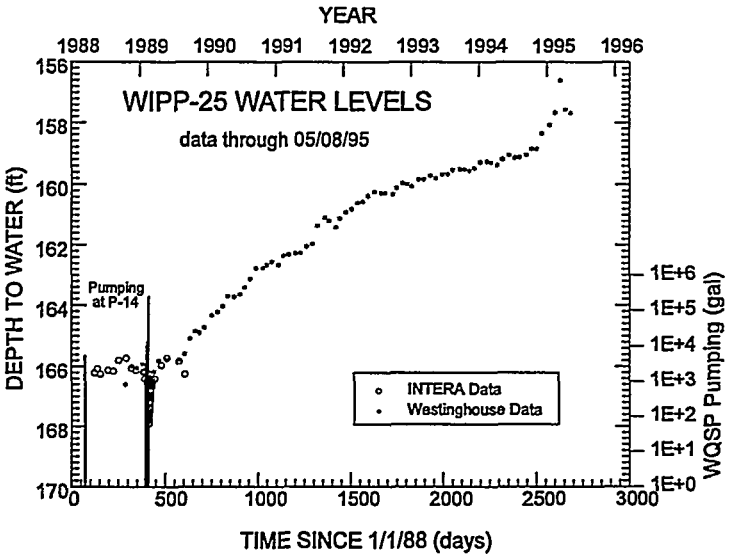


Figure 2.3-25. Well P-14 water levels.



WIPP-25, in Nash Draw, shows a rise. WIPP-25 is in a high permeability region and it takes a fair amount of water to change the water level.

Figure 2.3-26. Well WIPP-25 water levels.

WIPP-26 seemed to be rising, but now it seems to have stopped.

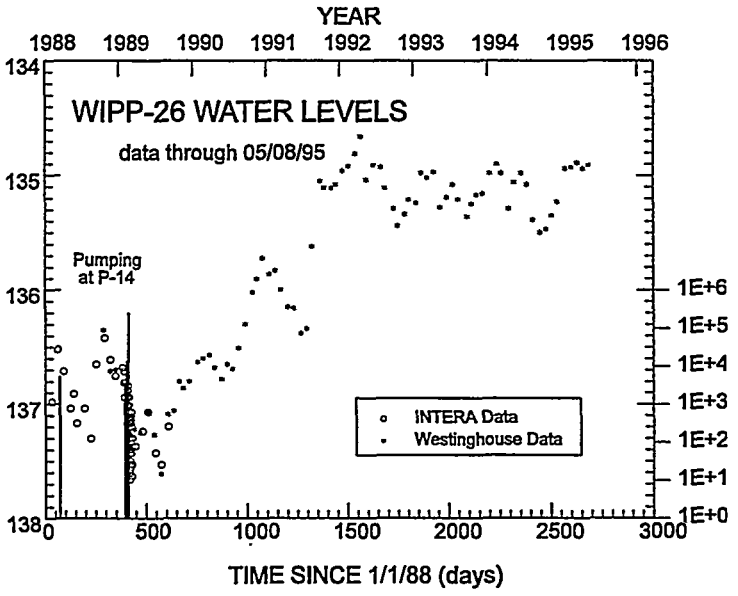


Figure 2.3-27. Well WIPP-26 water levels.

2.3.1.3 Northern Region

WIPP-27 is in the northern part of Nash Draw, very close to one of the potash mines. The potash mines discharge various amounts of effluent into Nash Draw depending on their production. When there is not much production, there is not much discharge into Nash Draw. When there is more mining and more refining, they discharge more. WIPP-27 has a lot of distinct features. The plot of water level rise does not exhibit the noise seen in the plot for WIPP-26. Instead, WIPP-27 is responding to

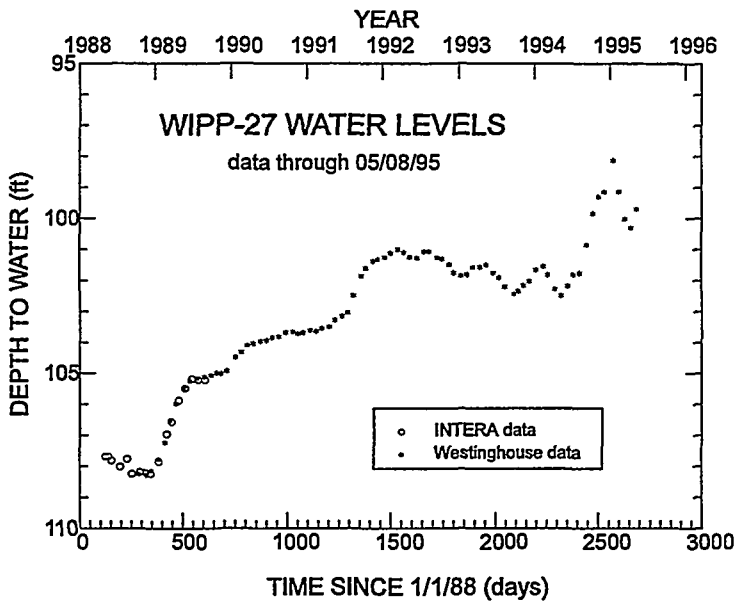


Figure 2.3-28. WIPP-27 water levels.

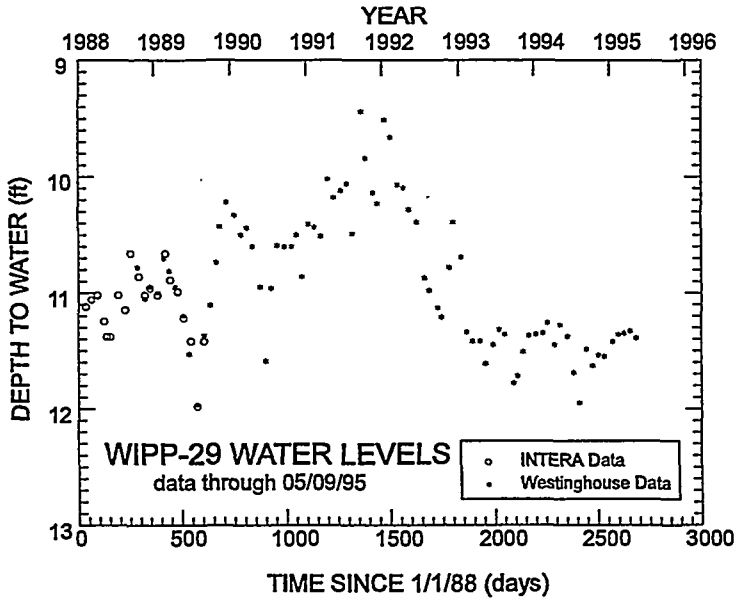


Figure 2.3-29. WIPP-29 water levels.

something fairly distinct. WIPP-27 appears to be providing a good indication of the discharge into Nash Draw. Some of these changes probably propagate through Nash Draw towards the northern part of the WIPP Site. But the changes get more diffuse as they get there.

WIPP-29 is so shallow, 11 feet to water, that it could be responding to almost anything.

WIPP-30 showed a rise, a stabilization for a few years, and now appears to be on another rise.

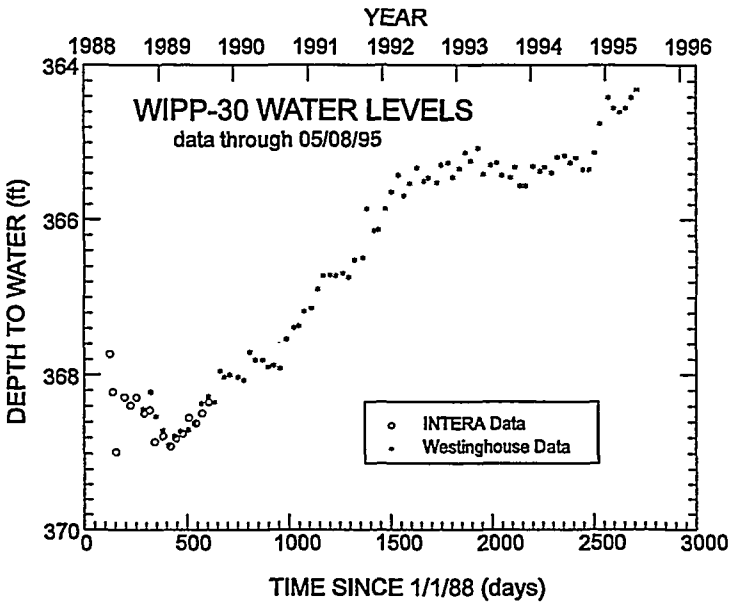


Figure 2.3-30. WIPP-30 water levels.

Well P-18 continues to rise. It is not clear where P-18 is headed. In contrast to all of the other plots, which begin in 1988, this plot begins in 1977. This is the complete water level history on P-18. Until

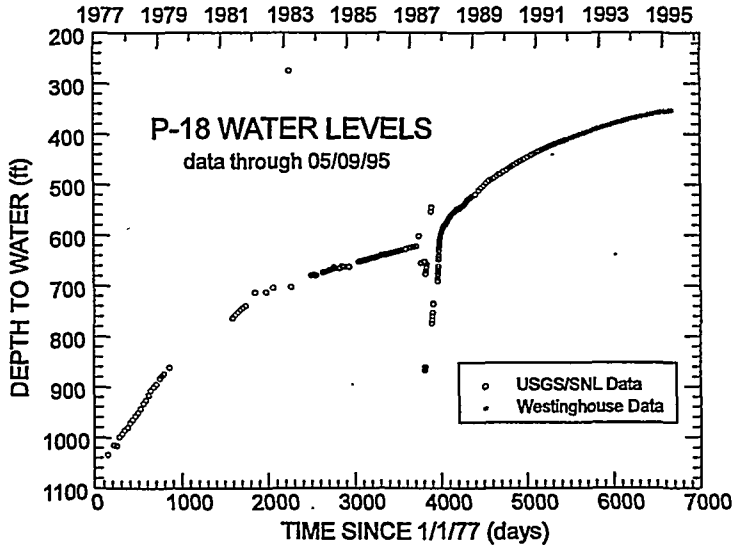


Figure 2.3-31. Well P-18 water levels.

about 1987, the water level was rising in a 4-inch well casing. It never actually stabilized. Then in 1987 we put a pip in the well. So, now the water level is rising in 2-3/8 inch tubing instead of 4 inch casing so it goes up faster because of the smaller diameter. The water level still hasn't stabilized there. A lot of people over the years, including myself, have hypothesized that we may not have the best connection to the Culebra in this well. There may be a problem with the cement bond. This is a cased, cemented, and perforated well. There may be a problem with the bridge plug at the bottom. There may be problem with the cement job. We don't have a lot of confidence that what we are seeing here is the Culebra.

2.3.1.4 Summary

To summarize, I see three different things going on with the water levels at the WIPP Site. To the south, centered around H-9, you see one very distinct water level rise that began abruptly in 1988, reached its peak at H-9 and seemed to propagate to the north, which I think is probably related to some kind of injection from some other well in that region. As you get to the center of the WIPP Site and more or less propagating out from the center of the WIPP Site you see recoveries and drawdowns related to events at the WIPP shafts. Those shafts are pretty well sealed right now, so the overall response you see today is rises in water level. As you move to the North and get into Nash Draw, I think you can probably see responses to the discharge of potash mill effluent into Nash Draw. I'm not sure about the availability of discharge records there. It might be possible to try to reconstruct a discharge history and try to relate that to the water levels we have seen. Again, I'm not sure that it's really relevant to WIPP compliance. The water levels and the flow directions are not from the WIPP Site towards Nash Draw. Any minor changes in gradient, in any event, are not going to effect the results of our performance assessment. We are not on such a hair trigger that a difference of 10% or even 100% is really going to make any difference.

2.3.1.5 Questions:

Dennis Powers: For wells H-7, WIPP-26, and WIPP-27. Are the data precise enough for annual changes?

Rick Beauheim: I have doubts about H-7. H-7 at one time pumped at 80 gpm and the responses we saw at the observation wells on the order of 100 feet away were dominated by earth tides. And the earth tidal responses were almost as great as the pumping test response. It may be of interest to no one but me, but earth tides are changes in water level affected by moon tidal affects and the changes in the configuration in the earth in response to tide. Actually, some of the first work on earth tides was done in Nash Draw, in the Culebra, back in the late 1920s, early 1930s. So H-7 is very close to the location where the very first earth tide research was done. The other ones, Dennis, -- yes I think it is possible that you could try to do that -- I'm not sure what you would turn up, but it might be worth a shot.

Tim Gum: Rick, on your model study where you indicated the 12 gallon per minute increases in fluid level, what was the total volume which had to be injected in order to get the total rise all the way?

Rick Beauheim: The way the modeling was done, the 12 gpm was turned on. I guess I'm not sure exactly when in 1988. In early 1988 this 12 gpm was turned on and was simply allowed to run for the duration of the modeling simulation. At the time that was done, the water levels were all continuing to rise. So the modeling was simply turned on and we watched the hydrograph to see if the simulator hydrograph matched what we observed.

Tim Gum: From 1988 on?

Rick Beauheim: From 1988 on to however long it ran. I honestly don't recall if we just ran a simulation through 1991 at the time or projected further. But we didn't turn it off and then on.

Tom Peake: Yes, do you think this affected your response times, due to rises from the South to the North, up to the Cabin Baby and H-4? Do you think that has any implications for suggesting that there are higher transmissivities in the South Central part of the WIPP site than are currently being modeled?

Rick Beauheim: I think you can look at the pattern of water level responses and learn something about the transmissivities. P-17 and H-17, for instance, lie on an east-west line. Yet their responses were different. I look at those two responses, H-17 and P-17, and what they say to me is there is a high transmissivity feature passing between those two wells. A few responses we observed tell me that the high transmissivity feature is more likely closer to P-17 than it is to H-17. Because the P-17 response seems clearer. It seems to catch the subtleties of the response better than the H-17 response. The propagation on toward Cabin Baby, H-4, P-15, I guess I really could not say whether it holds any surprises. I think it would provide an opportunity to take a closer look with our existing Culebra model to see if our current transmissivity distribution would match the responses that you see that much further away in detail.

Robert Neill: It is an extremely important area. In fact we have a half hour scheduled this afternoon to address this in greater detail. Rick, a quick question. Do you see any merit, at this point, in trying to obtain some water samples from these wells to examine, from a standpoint of chemistry, any change as both a function of location and a function of time?

Rick Beauheim: I really don't think so. We are looking at pressure transient propagation here which can be relatively rapid whereas actual transport of ground water is an extremely slow process. I don't think there is any chance at all of us seeing changes in water chemistry as a result of this.

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2.4. Observations of the Effects of Water Flooding on the Salado Formation

Dennis W. Powers, Consulting Geologist, Anthony, Texas

2.4.1 Synopsis

The Hartman vs. Texaco lawsuit and subsequent discussions with different people focused my attention on a physical condition common to several concerns. The basic physics or hydrology of liquid and gas movement laterally or vertically through the evaporites, especially the Salado, is common to decisions about oil and gas exploration vs. potash mining, deviated or vertical drilling through evaporites outside WIPP boundaries, and the fate of any gas generated by decomposition of waste at WIPP.

Exclusion zones for drilling and potash mining are presumed to be based on two principal concerns: safety and the desired development of resources. Exclusion zones presumably increase as real (or perceived) safety concerns increase; fewer resources are developed in consequence. Among the safety concerns is the possibility of lateral movement of hydrocarbons along evaporite beds from a leaking well into a mine. The same general setting can exist for WIPP from the nearest well to the underground workings. Gas generation at WIPP raised the possibility of movement away from the disposal mine to a boundary or well. And the Hartman Bates well raised the possibility of injected fluids reaching a well at a distance of about 2 miles from the injection field boundary and in a formation overlying the injection horizon.

Perhaps each situation has to be resolved separately (monetary settlement for Hartman, scenario analysis for WIPP, some other means for potash vs. oil and gas exploration). Nonetheless, as similar occasions arise, there will be a continuing need to understand the hydrology of liquid and gas transport parallel to bedding within the Salado or other rock units. There are probably no better investigations yet of these phenomena than for WIPP, and there will be increasing pressure to

understand and apply the results to different versions of the same fundamental problem.

2.4.2 Presentation by Dennis Powers

Today I want to cover a few different topics. The title that is listed for you is a little bit misleading. First, I want to give you a little bit of my impression of some things out of the Hartman vs. Texaco lawsuit that struck me. I also want to talk about some common problems, some underlying principles of physics that are important to several different projects and several different ways of thinking about the Salado.

Today, I am speaking on my own behalf and I am not here representing any organization at WIPP even though, I think most you are aware, I am under contract to one or more organizations to do work at WIPP. I am not a lawyer; this is not a legal analysis of the Hartman vs. Texaco case. I think that the comments that Bob Neill made at the beginning were important. This is not a rehash of that case. But there are some items of technical interest.

2.4.2.1 Background

Let's take a look at the setting for that well and the relationship to the Rhodes/Yates waterflooding unit principally operated by Texaco. In January 1991, Hartman and his company began to drill the Bates #2 well on an acquired lease that had previously been drilled by El Paso Natural Gas and had been producing for about 35 years before plugging and abandoning the Bates #1 well. The Bates lease is located in the southeast corner of New Mexico. It is located in the back reef and not in the Delaware Basin. It was drilled to try to produce Yates gas in the lease that Hartman had obtained. At about 2,240 feet the well begin to produce high volumes of high pressure brine. Drilling operations were stopped at 2,280 feet. The New Mexico Oil Conservation Division was notified. Out of concern that an underground blowout might occur, the driller was not allowed to

shut the well in for any extended period of time. Casing had been cemented back to the surface from about 456 feet in an approved drilling plan.

The flow, at times, was on the order of 1,200 barrels per hour. Nearly 300 truck loads of brine were hauled away and a pipe line was put in to take brine away to the South Leonard Waterflood Unit. It took five days to work out a final solution in consultation with the New Mexico Oil Conservation Division. That solution was to cement the annulus first, to go back in and check the cement job, and then to cement back to the surface, leaving the drill pipe in place. Thus ended Bates #2.

At that point Hartman and his company began to wonder where this had come from. The question that came up - was this a natural flow or was it not natural, that is, brought by some other means such as the water flood unit operated at Rhodes-Yates field? I am giving you some of my impressions and can't speak to the actual thought processes of anyone involved, but late last fall I was contacted. It appeared that there would be a defense during the legal proceedings that this was a natural event, that it was similar to the high pressure brines in the Castile Formation and several wells in the vicinity of WIPP. It bears certain resemblances to the data that had been obtained from underground testing at the WIPP — data that had been obtained by drilling small diameter holes and testing them with rather sophisticated means over a period of time to determine what the pressure buildup was. Hartman called me to see if I would be available to help counter these arguments. I spent some time reviewing the data and decided that the approach that they wanted to take was consistent with what I believed was going on so I joined their team, for a while, to provide consulting services. I was named as a potential rebuttal witness. I did not testify at trial. That gives you a little bit of a background. I thought that was important so you would know where I was coming from and you can judge accordingly whatever is said.

Some notes - the Bates #1 was drilled in 1953 by El Paso Natural Gas. It produced, again, for about 35 years and then was plugged and abandoned. The Bates #2 well is approximately 100 feet away from Bates #1 well on the surface. To my knowledge, there are no directional surveys. I cannot tell you how far apart they might be at the bottom of the hole which is about 2,280 feet.

At the point where the flow began, there is an anhydrite unit. It's on the order of 10-15 feet thick, based on geophysical logs from that well and nearby wells that can be correlated. We are in the Salado Formation. I have not tried to correlate the individual marker beds with those in the Delaware Basin. It's my guess we are somewhere in the range of marker beds 140 to 142, which would put it below the WIPP repository horizon, which is just above marker bed 139. There is, on the natural gamma log signatures for that drill hole and others, a slight gamma kick at the base of that anhydrite, which is consistent with what we see in shafts and drill cores and other logs of boreholes. But there is probably some clay or argillaceous zones besides anhydrite.

The distance from the Bates #2 well to the administrative boundaries of the Rhodes-Yates water flooding operations is approximately two miles. Structurally, the Bates well is generally updip.

2.4.2.2 Observations

The salt water blowout and the subsequent case raised interesting technical issues. One was the unresolved differences in the estimates of the true pressure in the Bates #2 well. The New Mexico Oil Conservation Division was concerned that if the well were shut-in, the high pressure brine would be injected into other formations (an underground blowout). Hence, the well could not be shut-in for an extended period of time to obtain a good bottom hole shut-in pressure. The consultants for Hartman believed that the best shut-in pressure came after the annulus had been cemented and there had been circulation and flow equal to the cementing job which should have relieved any pressure problem, or most of the

pressure brought on by a cementing job. That pressure was on the order of 1,000 psi at the surface. The consultants for Texaco had believed there was a more appropriate pressure that was several hundred psi lower. That would have brought the pressure gradient and the formation pressures down considerably from what the Hartman consultants had estimated. Nonetheless, the pressure measurements were less than desirable 1) because of the condition of the hole and 2) because of the inability to shut the well in and obtain a good shut-in pressure.

It was suggested that the pressure gradients can be used as indicators as to whether the water flows were induced by nature or induced by some other source. For the Rhodes-Yates water flood, the injection pressures at the surface ran 1,200 psi and above. Some injection pressures approached 2,000 psi at the surface. If those are correct, those surface injection pressures begin to produce pressure gradients greater than 1 psi per foot vertical. Typically, the measured pressure gradients from brine reservoirs in either the Castile or the very low flows in the Salado are considerably less than 1 psi per foot, ranging down to 0.8 psi per foot or less. The difference in pressures can be used to distinguish between natural or human induced occurrences.

There was testimony on both sides as to whether or not there were unaccounted injection fluids. The consultant for Hartman estimated that there might be as much as 20 million barrels of fluid that had been injected that was unaccounted for in terms of total production and storage capacity of the formation within the water flood unit. Consultants for Texaco testified that they did not believe, by their analysis, that there were any unaccounted for fluids.

There are differences between the geology at the Bates lease and the geology at the WIPP. The Bates well blowout was a large volume, high pressure flow. The bottom of the borehole was in the Salado Formation. The Castile does not exist in the area of the Bates well.

In the WIPP area there are high pressure, high volume reservoirs within the Castile. One brine reservoir was tapped at WIPP-12, approximately 1 mile north of the site center. Those kinds of brine reservoirs are in the Castile and are generally associated with a zone of relatively high deformation of the Castile, within a few miles of the margin of the Capitan Reef.

At the Bates #2 well, the Salado shows little deformation. It shows a general dip, but nothing of any magnitude comparable to the kinds of deformation observed in the Castile in the area of the Capitan Reef. The WIPP pressures from the Salado testing underground, suggests that the projected pressures will show a gradient on the surface much less than the Castile.

The Hartman-Bates well blowout raised interesting questions about expectations for institutional responses and institutional controls and how they change with time. Presumably they get better, but it is one thing that needs to be looked at.

There is a technical basis for scenario development. In the Hartman case, one has to either accept a natural cause or, if it is not natural, one must believe that fluid was transmitted along a bedding plane to the Bates lease perhaps for a distance of 2 miles. Transport along the bedding plane is the best explanation. For years the (WIPP) project has been concerned about gas, generated by waste degradation, either diffusing, fracing (fracturing), or otherwise moving along bedding planes. It is the same problem but moving in a different direction. With any kind of drilling, including water flood operation, around the boundaries at the site, the same issue comes back again. How are we going to address whether fluids can move along bedding planes or within the formation, a certain distance under different conditions? How will we address that?

BLM is having to try to address the issue, I believe, through litigation of the contrasting desires of oil and gas exploration vs. potash mining. How far away from mining is it safe to drill a hole or mine up to a hole? There are cases where mining has hit petroleum casing underground. That makes people nervous — that

there is an oil or gas well and that you get that gas leaking into a mine. Several things are going to happen. None of them are good. The most benign is that their expenses go up to try to deal with a gassy mine and they go out of business. It is not very benign. People are working with stock holders. That might be one of the more benign consequences, if such a leak did occur. But of course, every time you change that boundary, you say, well, we need to protect the potash and keep the oil and gas away. That just simply magnifies the amount of resources unavailable for both sides. Obviously, if you were going to maximize the resources, what you'd like to be able to say is "It's safe". You can co-exist. Everybody gets their way that way. So those are some issues that have some common problems.

What I see is that everybody will probably attempt to solve it uniquely because nobody likes to try to produce a general solution for all of the world. It is expensive and difficult. If you can produce a simple solution for your problem or concern or issue, whatever it might be, if you can produce that solution for yourself very simply, you'll do it. But it might be good for the different organizations to be thinking about this with a little bit longer term (framework) and to recognize that there may be consequences, even unintended consequences, from one solution to another one's problems. Even if it's a modeling approach that makes certain assumptions that the modeler says don't cause a problem, somebody else might have some difficulty with those assumptions. We need to make sure that those are specific, unique, and identified as being adequate for that problem but not necessarily general assumptions. Those are a couple of the things I wanted to talk about this morning. I believe that the pressure on the WIPP underground data and related data from the WIPP will increase. By pressure I mean there will be a lot more demands for it and a lot more desire to interpret it, to make sense out of the particular application that you have, from BLM trying to resolve oil and gas versus potash mining, to other people. They need to be

aware of that and to think about how best to integrate interactive folks. Thank you, any questions?

2.4.2.3 Questions:

Wendell Weart: Do you know, Dennis, if there is presently a standoff distance, either legal or practical that the industries have used to keep certain separation between potash excavations and petroleum holes?

Dennis Powers: The number I heard was 500 feet but I also know that some of the potash mines have generally, inadvertently drilled into a few, or mined into a few holes, too. Five hundred feet is the number I heard but I haven't seen it written down in some regulatory fashion - it may be there. And there may be somebody that knows that number better than I do.

Dan Stoelzel: You said there has been inadvertent mining into petroleum wells. To your knowledge, is there any record of gas leaking into these mines?

Dennis Powers: I haven't seen any, no. What they did, the records that I saw, indicated that the casings got marked up. Tungsten carbide bits will do that. And then there were various measures to go ahead and protect the drill casing. In one case, I'm trying to remember which mine it was, there was a caisson built and a big cement block support around it.

Dan Stoelzel: What about naturally occurring gas in the potash mines?

Dennis Powers: Well they are not classified as gassy mines with methane residence, but there are occasionally these blowouts of gas which have been trapped, most of which is nitrogen. Lokesh [Chaturvedi] has written, edited, and put together a volume that discusses gases occurring in the Salado Formation. That's one good source and there are other sources within some of the Sandia publications that describe some of the gases. But basically it is nitrogen-dominated and few other minor gases. But potash mining people desperately wish

to avoid the gassy classification because if they ever wind up in a gassy classification, at least at this point, they'll be out of business. And right now I don't see any — there is no particular reason to fear that, as far as I know.

Chuck Byrum: Dennis, do you know why they inadvertently hit some well bores while they were mining?

Dennis Powers: No. It may be known, I just don't know.

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2.5 Geologic Considerations and the Implications for Waterflooding near WIPP

Lori J. Dotson, Sandia National Laboratories

Current Petroleum Practices and their Application to WIPP area Development

Daniel M. Stoelzel, Sandia National Laboratories

2.5.1 Combined Synopsis

A Rhodes Yates/Vacuum Field scenario (where injected water migrated to the overlying salt) is highly unlikely at WIPP because of: differences in geology, changes in oil-well completion practices from the 1940's, and improved reservoir management. In addition, new state regulations are in place to reduce the possibility of a petroleum well leaking into the Salado.

The differences in geology between WIPP and the Vacuum and Rhodes Yates Fields is significant. WIPP is located in a fore reef environment where a thick zone of anhydrite and halite (the Castile Formation) exists. Oil production is from the Brushy Canyon Formation at depths greater than 7,000 feet (5,000 feet below the WIPP repository). By contrast, the Castile Formation is missing at both the Vacuum and Rhodes Yates Fields which are located in reef and fore reef environments, respectively. Oil production at the Vacuum Field is from the San Andres and Grayburg Formations at depths of approximately 4,500 feet and oil production at the Rhodes Yates Field is from the Yates and Seven Rivers Formations at depths of approximately 3,000 feet. At the Rhodes Yates Field, for example, there is only a couple hundred feet of vertical separation between the Salado Formation and the waterflood injection zone. In addition, the oil pools near WIPP are characterized by channel sands with thin net pay zones, low permeabilities, high irreducible water saturations and high residual oil saturations. Therefore, large-scale waterflooding near WIPP is unlikely. The estimated life of the pools near WIPP is less than 10 years for primary production and less than 10 years for secondary production.

The petroleum industry has made many advances since the time when the Vacuum and Rhodes Yates fields were first developed. Improvements in drilling, casing, and cementing technology have greatly reduced the occurrences of leaks in oil wells. An industry-wide effort to reduce formation damage and increase production has led to improvements in completion design and advances in stimulation. Open-hole (non-cased) production/injection wells and nitroglycerin treatments are no longer used. Acid stimulation and hydraulic fracturing techniques have improved considerably in the last ten years. Service industry support has made this technology available to both the large and small operator. The availability of inexpensive software has lead to improved reservoir management, including waterflood design.

State regulations require a salt isolation casing string for all wells drilled in the WIPP area. Injection pressures are not allowed to exceed fracture pressures for all injection/disposal wells. Operators obey these regulations because the State has power to levy fines and/or shut wells in, should they become aware of a violation.

In conclusion, geological differences, modern petroleum development practices, and regulatory oversight will greatly reduce the risk of oil wells leaking to the Salado in the WIPP area.

2.5.2 Geologic Considerations and the Implications for Waterflooding near the Waste Isolation Pilot Plant - Presentation by Lori J. Dotson

There are three main points I'd like to make here.

1) The oil pools near WIPP are relatively small scale when compared to the Vacuum Field and the Rhodes Yates Field.

2) Large scale waterfloods are unlikely. It is not a foregone conclusion that all of the fields will be waterflooded or that any of the fields will be waterflooded.

3) Most importantly, there are a lot of geologic differences between the Rhodes-Yates Field, where the Hartman-Bates well was and WIPP. For one thing there is five thousand feet of vertical separation between the producing interval, at WIPP being the Brushy Canyon Formation of the Delaware Mountain Group and the WIPP repository. It is true that there is salt water disposal in the Bell Canyon Formation, but that is still a vertical separation of about 2,500 feet. In contrast, at the Rhodes-Yates field, you are only looking at a vertical separation of a few hundred feet between where Texaco was water injecting and Hartman encountered the blowout. The Vacuum Field is being produced from the San Andres and Grayburg Formations at approximately 4,500 feet. The Rhodes-Yates is being produced from the Yates and Seven Rivers Formation which is located about 3,000 feet below the ground surface. The producing interval of the Brushy Canyon is located about 3,000 feet below the Bell Canyon. The Castile Formation is present at the WIPP Site but is absent in the backreef at the Rhodes Yates Field.

As to the second point, about generally small pools and thin pay zones, at Livingston Ridge and Lost Tank, you heard Ron Broadhead talk about forty foot of net pay. That's where it is economic to produce oil. There are a lot of wells in the Livingston Ridge area where there is only ten to twenty feet perforated

casing. So there are some pretty small pay zones. In contrast, at the Vacuum Field, one block that I looked at had three hundred feet of gross pay. So we're talking not an order of magnitude difference, but close to it. In the Los Medanos and Sand Dunes there are pay zones that range from less than twenty feet up to one hundred forty feet.

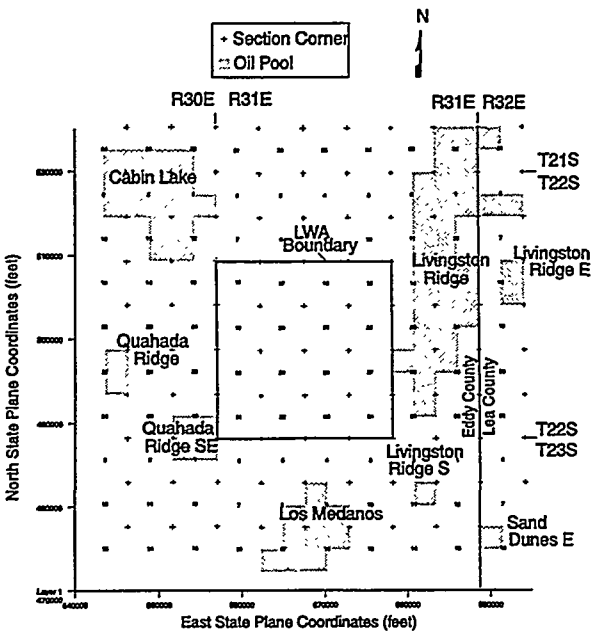


Figure 2.5.2-1. Producing oil field leases surrounding the WIPP.

Another point that Ron made that was really good, the primary production from area around WIPP from the Brushy Canyon is going to be less than ten years and for secondary production, less than ten years of secondary recovery. Production from these fields is going to play out in less than twenty years. Water injection, if water flooding took place, would be less than ten years. Just to give you a reference, the Vacuum Field for instance, over 300 million barrels of oil and 200 BCF of gas have been produced. I will have to get the exact figures from Ron, but we will have to leave that for the discussion. But we are looking at order of magnitudes difference between what is going on at the WIPP area and what we have at some of the larger fields.

This last point, the reservoir characteristics, the 7 to 24 millidarcies is actually a number for the Bell Canyon. The information for Brushy Canyon is actually pretty scarce and the characteristics of the Brushy are such that the permeability

would actually be less. The Brushy Canyon is siltstone and sandstones, but also there is authigenic clays which tend to clog the pores and reduce the permeability somewhat. What this means is that water flooding could occur, but they may have to space the injection wells closer. But then you get into an economic question. There is a technical question and an economics question. It just may not be economical to drill additional wells. The reservoir is also characterized by highly irreducible water saturation and high residual oil saturation. That emphasizes my previous statement. Yes, you can waterflood these fields, you can waterflood those that have better characteristics, but it is an economics issue. If you have to drill additional wells, it may be too costly to get that oil out.

Cross-Section Depicting the Relative Locations of the Rhodes Yates Field and the WIPP Repository

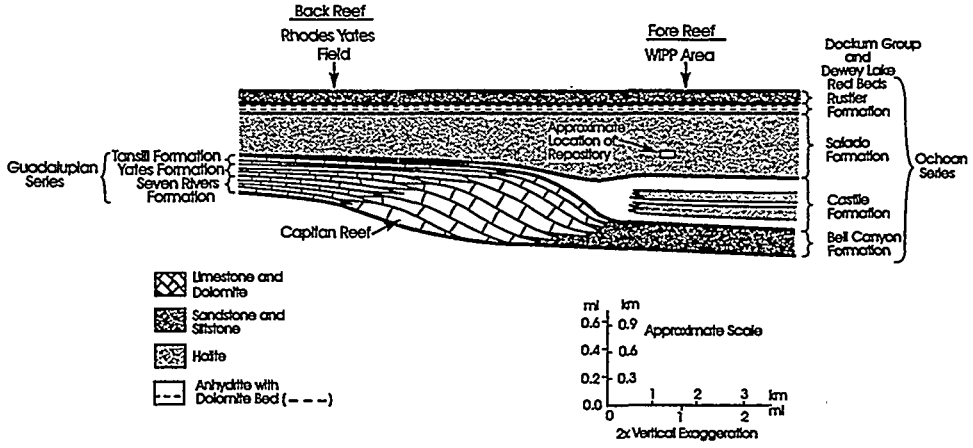


Figure 2.5.2-2. Cross-Section of Rhodes Yates Field and WIPP.

I really wanted to focus on the difference in the vertical separation at WIPP versus Rhodes-Yates which this figure illustrates quite nicely.

At the Vacuum Field, the permeabilities are up to 400 millidarcies. There is an order of magnitude difference. At Vacuum, like I already said, the pay zones are much thicker.

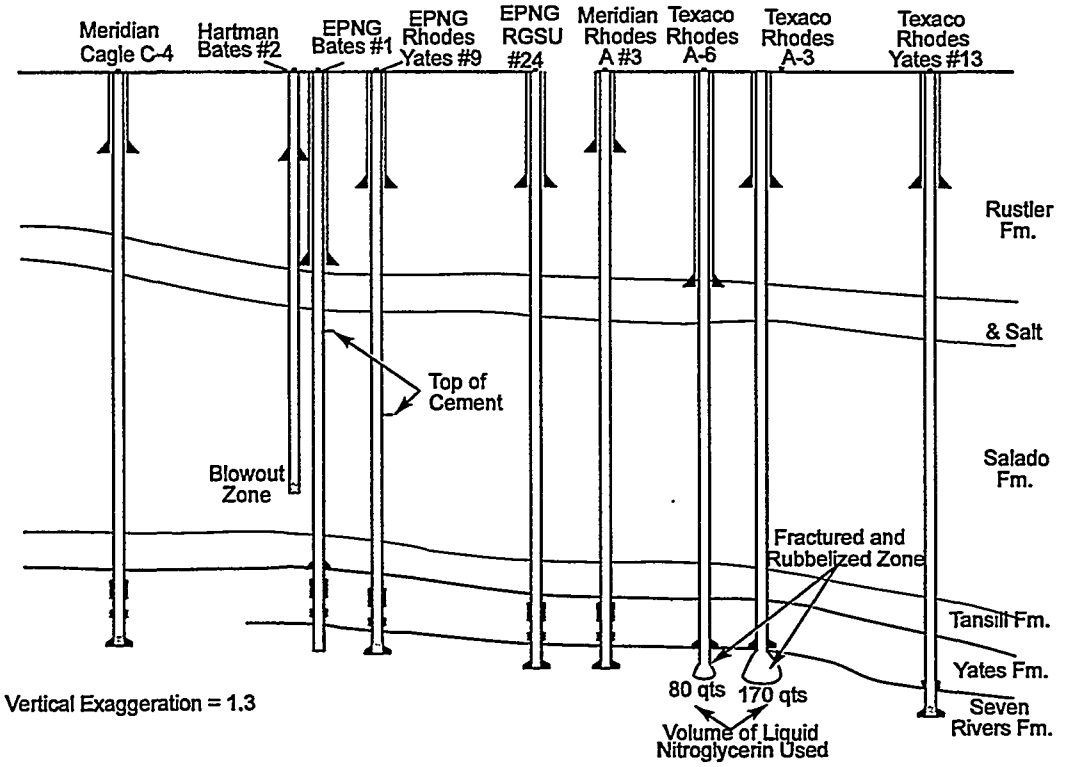


Figure 2.5.2-3. Schematic showing location of Hartman Blowout and Texaco Injection Zones.

This is a schematic showing where the Hartman well blew out and where you have water injection from the Texaco wells. Back in the "old days" a well was made more producible by pouring liquid nitroglycerin down the wells and basically just blow up the formation. So there are rubble and fractured zones. You don't know where your fluid is going at all. Like Dennis Powers stated, I also do not wish to comment on the legal issues of the Hartman-Texaco case. There were clearly practices that occurred back then that are not practiced now. Some of the casing, cementing, and developmental practices will be covered by Dan Stoelzel in his presentation. Between the Hartman blowout zone and the Texaco injection zone, there is hundreds of feet of vertical separation and also the

suspect casing and cementing jobs. The figure shows where the surface casings are set. It is unclear from this figure what they are actually casing off. Some of these don't look like they extend down to the Culebra. There are really strange well constructions there.

Three main points:

1) Potential waterfloods near WIPP would be relatively small scale. I'm not saying that they would or would not waterflood, but it would be small scale if they occurred.

2) The fields will play out in less than twenty years. I think we are all in agreement on that.

3) The interval where they would inject water for a waterflood is 5000 feet beneath the WIPP repository. So you have quite a distance it would have to travel vertically to affect the repository.

2.5.2.1 Questions:

Wendell Weart: When were the injection wells completed - in what time frame?

Lori Dotson: This is something that Dan (Stoelzel) has more information on. In the Vacuum and Rhodes-Yates fields, for example, we are looking at the 30s and 40s and I think some of them in the 50s. But they are older wells, older construction. I hate to keep pushing everything off to Dan, but he has some really nice schematics that show the differences in well construction from the 30s and 40s to the present time. You are looking at wells that are over forty years old.

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2.5.3 Current Petroleum Practices and Their Application to WIPP Area Development - Presentation by Dan Stoelzel

With the older well completion techniques, especially in the Rhodes-Yates Field and Vacuum Field, there has been communication behind pipe caused by situations such as bad cement jobs. In these fields the injection wells were in communication with the overlying strata. In the Vacuum Field, for example, there was concern that some oil field injection wells would contaminate the Ogallala fresh water aquifer. The problems with the Rhodes-Yates waterflood were covered in previous presentations.

The possibility of water injection wells endangering the WIPP is highly unlikely. Neither a Rhodes-Yates nor a Vacuum field scenario will happen at WIPP because of the differences in geology, changes in oil well completion practices from the 1940's, and improved reservoir management. Current industry practices and controls that are in place reduce the risk of injection or disposal wells endangering the WIPP site. There have been changes in the petroleum practices from the 1930s and 1940s and 1950s, even up through the 1970s, versus today. New regulations, mainly statutory regulations, have come into effect. The presentation is divided into the major areas of drilling technology, production and completion technology, and reservoir management. The last 10 or 20 years have seen numerous advances in these areas.

2.5.3.1 Drilling Technology

Since the 1940s and 1950s, there have been considerable improvements in the cement that is used to cement the casing - higher bond strengths, better cement properties, and impermeable cements. Drilling mud technology has improved to limit pole washouts and lost circulation problems. This is especially true when drilling in familiar geology. Lost circulation control becomes a fairly exact science. This is important in the casing stage of a well. If there are lost

circulation problems and washout problems, this could lead to communication or leaks behind pipe. Prudent operators know that any kind of leak behind a pipe is detrimental because it could lead to a loss of production, loss of reserves, and loss of revenue. Compared to drilling operations of the 1970's and early 1980's, drillers have a better understanding of operations such as block control and controlling kicks.

There have been numerous improvements in the last 10 to 20 years in corrosion control. Casing and tubing strings are inspected on the surface prior to running in the ground to eliminate potential leaks before running the casing. There are corrosion inhibitors that are routinely pumped into the tubing and casing to limit corrosion problems. Casing strings are routinely pressure checked. State regulations also mandate pressure testing of the casing. There is a lot of research and development in all these areas.

One point that hasn't been brought out yet is that most of the players in the Delaware Basin area, especially around WIPP, are small time operators. The smaller companies generally don't have the big research and development to support their oil and gas development. However, much research is transferred to the smaller companies through the service industry.

There have been significant advances in directional drilling and horizonal drilling in the last 30 years, but especially in the last 10 years. The costs for directional drilling have come way down. This is important for potential WIPP development because it is feasible to tap into much of the possible and probable reserves by directionally drilling from a surface location outside the land withdrawal area.

2.5.3.2 Completions

Once a well has been drilled and cased, substantial technology is used to develop the pay interval. There have been considerable improvements in perforating technology, tubing packers, gravel packing, well stimulation, fracturing, and acid

stimulation. Open hole completions are rarely used in the industry and are definitely no longer used in the WIPP area. Generally, the production interval is cased and perforated. There have been advances in shape charge perforators, stimulation, and in hydraulic fracing technology, especially in the area of predictive modeling over the last ten years.

There have been substantial developments in fracture height control. Generally, oil companies do not want to hydraulically fracture out of their producing zones. To fracture out of zone could translate to loss of reserves. Operators definitely do not want to exceed fracture pressure in an injection well. The whole purpose for a waterflooding injector is to maintain pressure or inject into a producing horizon. If the operators are injecting out of zone, they are losing reserves.

Acid stimulation has come a long way. Acid stimulation is designed to specific rock types and fluid types.

2.5.3.3 Production

There have been numerous advances in wireline, coiled tubing workovers, and through tubing workovers that greatly reduce cost and could extend the economic lives of wells.

The preferred method of lift in the WIPP area is the sucker rod pump. However, there are alternatives such as gas lift, submersible pump, or plunger lift. Each of these have seen a lot of development in the last 10 to 20 years.

Routinely, coated tubulars are run, especially in injection wells because injection wells are recognized as a highly corrosive environment. Multiple completions are possible. By running dual completion strings, two or more zones can be simultaneously produced. Behind pipe reserves are typically recovered by successively plugging back as the operator comes up the hole.

Leaks are not good. If an operator is aware of a leak, he will generally take remedial action to fix that leak. The state is the regulatory agency that requires frequent pressure checking of tubing and casing. If a leak is detected, the operator must repair the leak.

2.5.3.4 Reservoir Management

One improvement in reservoir management includes the advent of affordable personal computers (PCs) and the availability of inexpensive software. During the last five years there have been significant advances in relatively inexpensive software to run on PCs. Whereas, the small company of the past didn't have the manpower or the money to afford this type of luxury item, now it's fairly routine. Various research firms and universities provide software support. Availability of the software has especially assisted the small time operators to optimize field development and field production.

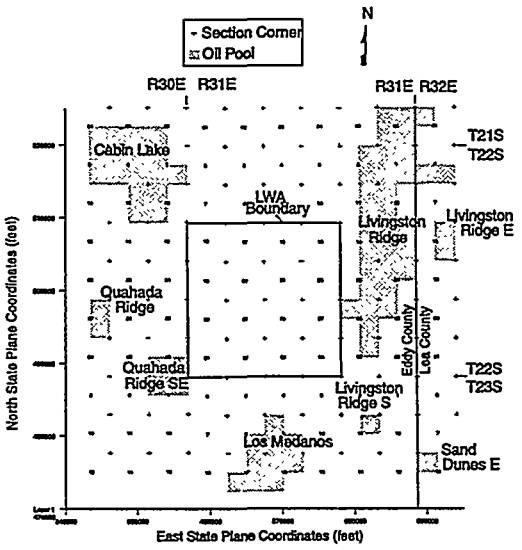


Figure 2.5.3-1. Producing petroleum leases adjacent to the WIPP Site.

The five spot water flood pattern is being used at Rhodes-Yates Field and at the Vacuum Field. However in the WIPP area it is highly unlikely that a five spot pattern would be used, especially with small pools. The decision to convert a well to water injection, in most cases will be more determined from the reservoir geology and geometry. For example, the Livingston Ridge Lost Tank Field is a channel sand. An in-line injection flooding pattern would be more likely. In this case, injectors

would be located in the southern part of the field and drive oil updip to the producers to the north. For these small pools a five spot water flood pattern would be highly unlikely both economically and geologically.

Source water compatibility between the formation rock and the injected fluids is very important. This is relevant to the WIPP area because there has been some speculation that a future driller may decide to use, for example, Culebra fluid as source water for an injection project. This is highly unlikely. The oil bearing formations contain authigenic or interstitial clays. If less saline water was injected into such a formation, it would cause clay swelling and potential plugging of pore spaces. Injecting Culebra water would essentially ruin the well. At this time, none of the injection wells or disposal wells are using the Culebra for source water. And I expect that will be the same forever. Operators will typically find their source water from the same formation as their oil production.

In addition to source availability, economics is the big question. Can small operators afford the surface facilities and the additional costs to drill injection wells or convert producers into injectors? The small oil companies typically have fairly shallow pockets. A water flood requires substantial capital. The return on the investment will be several years down the road in the producing life of the field. Most small companies wouldn't be able to weather that economic return.

The amount of water being pumped into a pool is a direct function of your recoverable reserves. In the WIPP area, the oil is found in small pools. The operators are not going to be injecting large volumes of water, especially in view of the 10-20 year life that most of these pools will last through secondary recovery. In an injection project, operators will stay below the fracture pressure of a formation. Operators don't want to fracture out of zone and pump water into an unknown formation where it is not beneficial to their productive horizon.

2.5.3.5 Wells in the Vicinity of WIPP

The James E #12 well is operated by Phillips and produces from the Cabin Lake Pool. In 1988, the State of New Mexico published regulations on completing oil and gas wells in the potash area, which includes the WIPP area. There was concern about natural gas potentially leaking into potash mines. In the Vacuum Field, the State had seen communication potentially into both the Salado and the Ogallala. The state now requires all the oil and gas operators in the potash area to include a salt isolation casing string in their well design. The surface casing typically runs through the upper stratigraphic units such as the Dewey Lake Redbeds and the Culebra. The intermediate casing, which is required by the state, is cased off below the salt formations, the Salado and the Castile. The state also requires that production casing run to the surface.

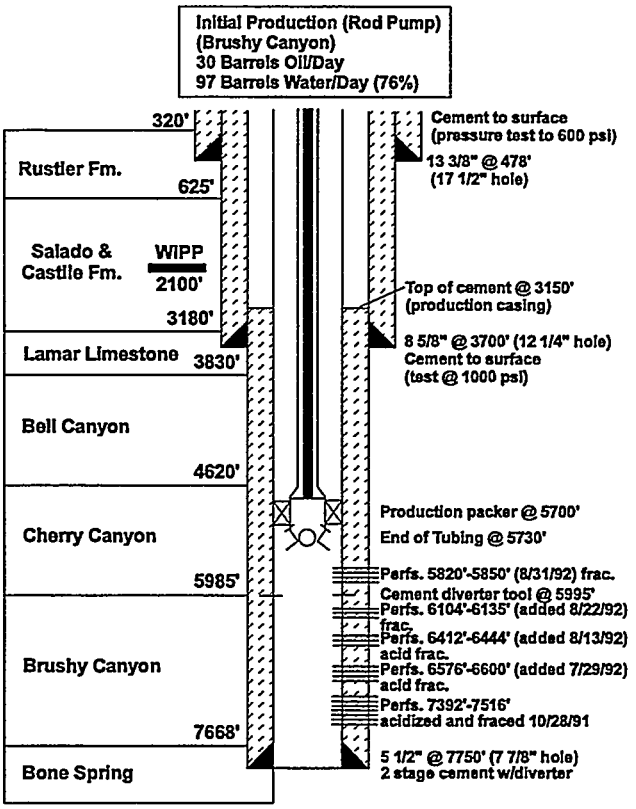


Figure 2.5.3-2. Typical Cabin Lake Pool Completion (James E#12).

The James Ranch Unit #19 well is operated by Enron and produces from the Quahada Ridge Delaware pool. The top of the cement surrounding the 5 1/2 inch production casing is at 2,680 feet. The bottom of the 8 5/8" salt isolation casing is at 3,850 feet. There is about 1,200 feet of cement as well as two sets of casing strings to help isolate the salt. The James Ranch Unit #19 is one of the better producing wells. The initial oil production rate was 213 barrels per day. The initial water production rate was 240 barrels of water per day. Initial production was over 50% water. We also see high water production from the Livingston Ridge. Seventy-six percent of the fluid production was water. These fields have a high water content and produce large volumes of the moveable water.

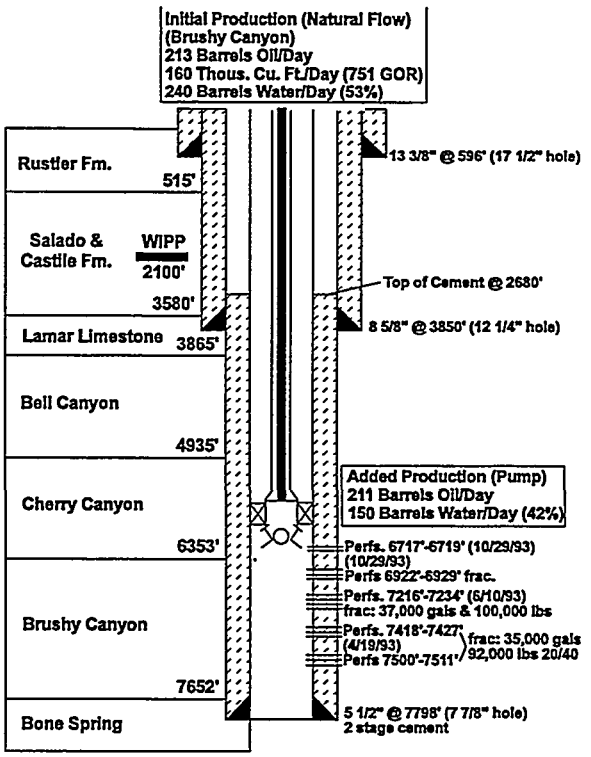


Figure 2.5.3-3. Typical Quahada Ridge Delaware Pool. James Ranch Unit #19.

A typical Livingston Ridge completion and a Morrow gas producer completion are shown. Each schematic shows a salt isolation string. For illustration purposes the WIPP horizon is also shown. The vertical separation between their production perforations and the WIPP horizon is on the order of 5,000 feet or more, which is much greater than that of the Vacuum Field and the Rhodes-Yates Field.

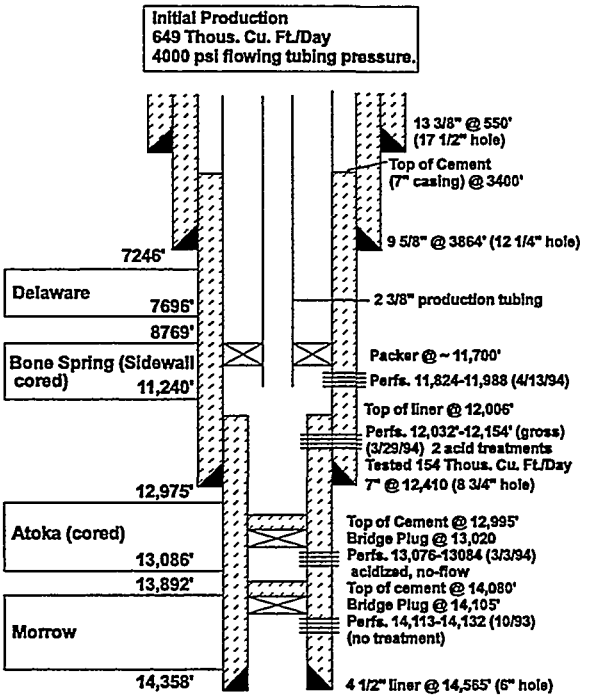


Figure 2.5.3-4. Typical Los Medaños Morrow Pool Apache 25 Federal #2.

The Morrow schematic illustrates the success of the plugback technique used by most operators. Probably the only reason this well is economical is because it has multiple pays. This well was originally perforated in the Morrow gas. It came in at a very high rate for this area, over 600,000 cubic feet a day. It was originally completed in the Morrow Formation in October 1993. By March 1994 this interval had been plugged back and the well completed in the Atoka Formation. In less than a year, this Morrow pay had depleted. The lower Atoka was tested but didn't have sufficient flow rate. The lower Atoka was plugged back and the well was completed in the upper Atoka.

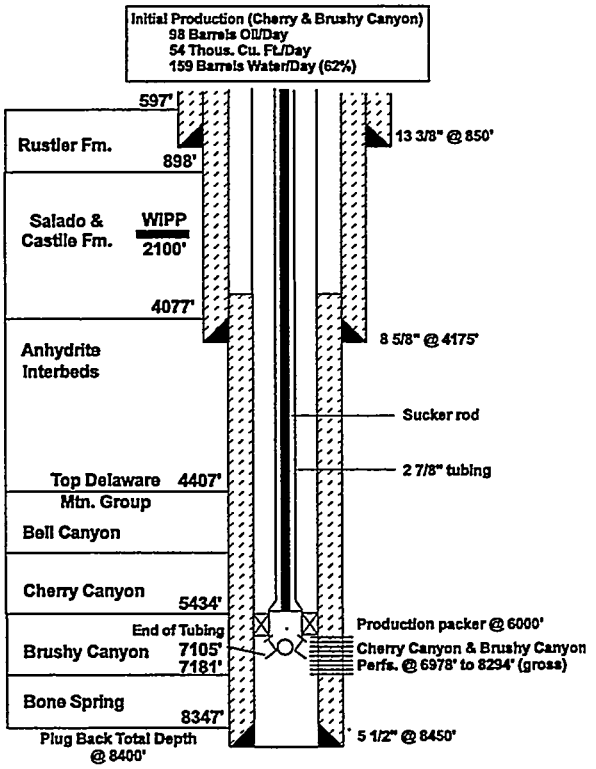


Figure 2.5.3-5. Typical Livingston Ridge/Lost Tank Completion.

The well is apparently producing from the upper Atoka, although this formation may also be plugged back. The information comes from the New Mexico Oil Conservation Division in Santa Fe. There is a six month to one year time delay on the Sundry Reports, so the information on these wells may be outdated.

2.5.3.6 Early Well Completion Practices

For comparative purposes, the schematics of the Vacuum Field and Rhodes-Yates Field completion are shown here. I didn't have direct well data for these wells. In the case of the Vacuum Field, the discovery well was drilled in 1929 with a cable tool rig. It wasn't developed until the late 1930s and early 1940s. Common practice, during that time, especially in carbonate formations where there is low flow due to tightness, the operator would nitro-frac the completed well. This is a general schematic of their discovery well. It was nitro-frac with 580 quarts of nitroglycerin. I'm not an explosive expert, but I would think that 580 quarts could do considerable damage not only to the formation but to everything else down there.

In the 1930s and 1940s the oil and gas industry was in its infancy. Safety issues, reservoir management issues, and formation damage issues were pretty much nonexistent. Since then, there have been substantial improvements. Similar to the Vacuum Field, the Rhodes-Yates fields were also nitro-fraced. An important thing to note about the typical Rhodes-Yates early completion is the small amount of separation from their open hole productive horizon from here to the Salado, approximately 100 to 200 feet. Furthermore, the wells were nitro-fraced.

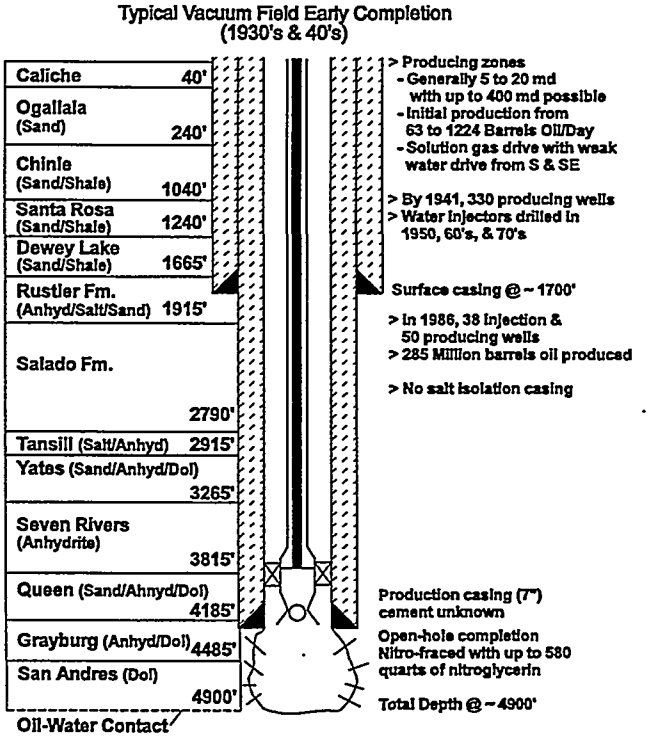


Figure 2.5.3-6. Typical Vacuum Field Completion for 1930s and 1940s.

Originally these early wells were drilled as producers in the 1940s, 1950s, and 1960s. As many of these production wells watered-out, they were reconverted to injection wells. They just pulled sucker rod pumps out and maybe changed out the tubing string. They didn't take any remedial action as far as casing this open hole interval or cement squeezing behind the body to isolate. They just turned it right around and started injecting into this thing. So it is no wonder that there is considerable potential for injection fluid to go anywhere other than where they want it to go. It is going to the path of least resistance.

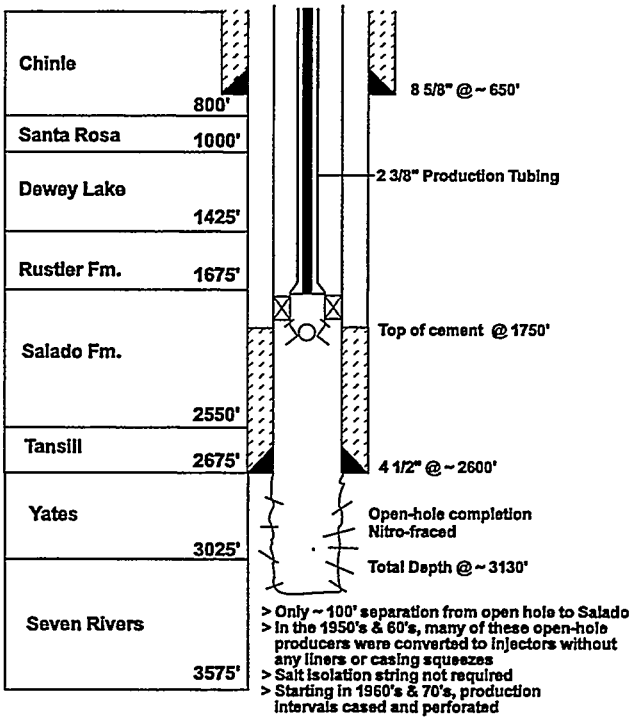


Figure 2.5.3-7. Typical Rhodes Yates-Seven Rivers early completion, 1940s-1950s.

The state rule on the salt isolation casing didn't come into effect until the late 1980s. Both these fields, the Vacuum Field and the Rhodes Yates Field, did not have salt isolation casing. As shown, the Salado is just behind one casing string. Early cementing and completion practices were such that, who knows where the cement went when they pumped it. A lot has improved since the days of these wells.

An older well, Todd 26 Federal #3, is shown. Todd 26 Federal #3 is the suspect well, about one and a half to two miles offset from the H9 WIPP test pad. It was here that Rick Beauheim observed the water table fluctuations. The rises in the Culebra due to potential leaking was attributed to this well. After looking at this schematic, I tend to agree with that. This well was completed in 1971. Originally it was drilled as a Cherry Canyon test well that was probably nonproductive. The well was converted to a disposal well. There was no salt isolation casing and it was an open hole completion somewhat similar to the Rhodes/Yates Field or Vacuum Field situation. This well was a disposal well for about 20 years. It is now plugged and abandoned. I am not sure when that was. I am trying to find out from the New Mexico Oil Conservation Division (NMOCD). There are very few records on this well. However, it is no longer disposing salt water.

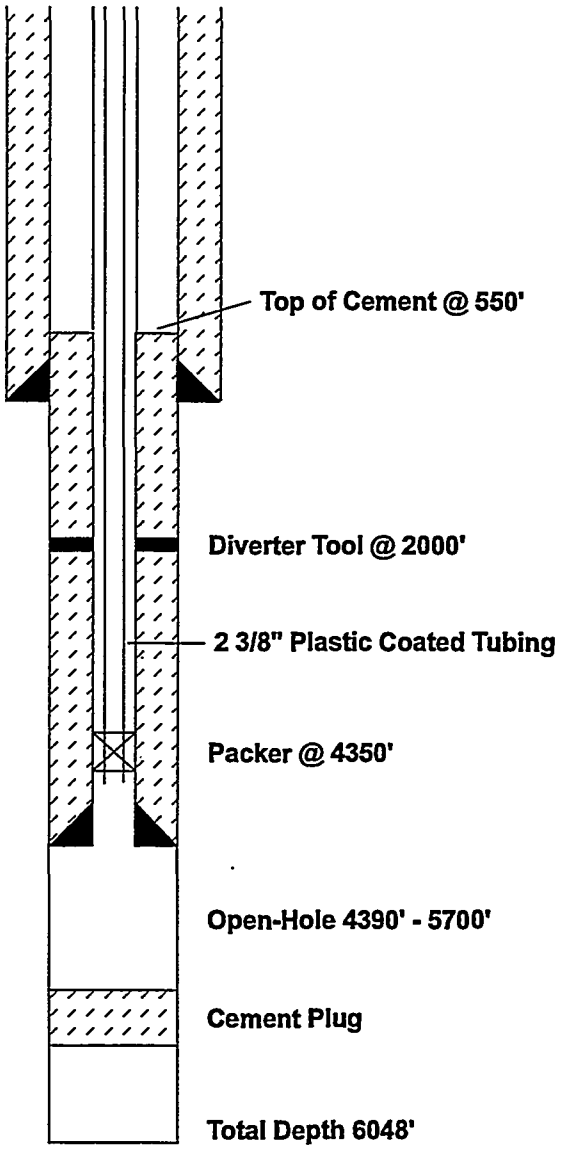


Figure 2.5.3-8. Texas American Oil Corporation Todd 26 Federal No. 3 Water Disposal Well.

A current salt water disposal design planned for the Livingston Ridge Field is shown. The plan shows the salt isolation casing. The production casing is run through the interval and perforated. The well was originally a strong producer. It is not uncommon to convert watered-out or nonproductive production wells to disposal or injection wells, which is the case for this well. The Sundry intent was filed on September 24, 1992. Surface injection pressure for this well is limited to 750 psi which is below fracture pressure. New state regulations require that operators stay below fracture pressures, either below 0.2 psi per foot above the hydrostatic gradient or below the fracture pressure as determined from injectivity tests.

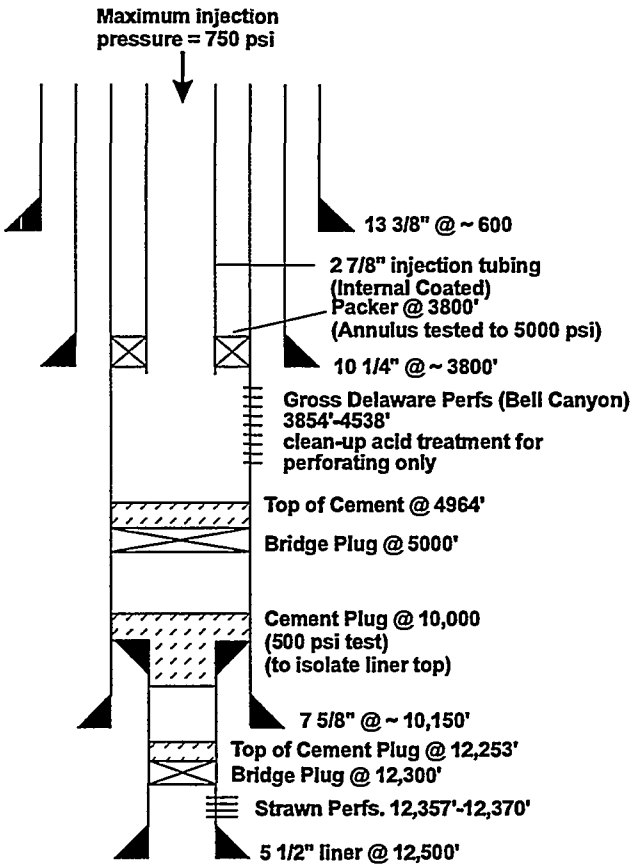


Figure 2.5.3-9. Current Salt Water Disposal Well Livingston Ridge Federal #9. Intent filed September 24, 1992.

2.5.3.7 Questions:

Robert Neill: Dan, you give a very compelling case for some of the current drilling practices and plugging practices. It is a great improvement over what has been done in the past. On the EPA standards, one is talking about what will be the behavior for human intrusion over long time periods. How comfortable do you feel with commitments requiring operators to keep injection pressures less

than fracturing pressures and then going to EPA and arguing that this will continue to be true in the long term future.

Dan Stoelzel: I think it highly likely. Like anything the oil business does, it is driven by economics. Nobody can predict the price of oil in the future which is the governing driver for anything an oil operator does. These regulations are put into effect because of the experiences of the oil companies — the isolation string and the requirement not to exceed fracture pressure. That is not only a regulation but like I said, a common practice with the operators because it is not a good thing to exceed fracture pressure in injection wells. I think it is highly likely that if anything, more constraints and regulations will come into effect or if nothing else, it will remain the same. The industries evolved to this point and because of this we are getting a lot more reserves out of the ground than we did back in the 40s and 50s. You know it is a learning process and I think the oil industry is reaching the top of that curve. They have come a long way.

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2.6 Potential Effects of Oil and Gas Activities on the Salado and Overlying Formations

Matthew Silva

2.6.1 Synopsis

The EPA assurance requirements for the disposal of transuranic waste include the requirement that the site should avoid places where there has been mining for resources, where there is a reasonable expectation of exploration for scarce or easily accessible resources, and where there is a significant concentration of any material that is not widely available from other sources. The WIPP is sited in an area with a 64-year history of commercial mining in a potash enclave which represents 57% of the nation's potash reserves and 80% of the nation's domestic production. Further, there are substantial reserves of oil and gas in the vicinity of the repository.

It has long been recognized that oil fields in southeast New Mexico, overlain by the Salado Formation, have problems with waterfloods. For waterflood projects in Lea County, Ramey (1976) noted that water injected at around 3,600 feet was escaping from the injection interval, migrating upward to the base of the salt section and then moving horizontally through this section. Waterflows of 5,000 to 6,000 barrels per day and a recorded surface pressure of 1,600 pounds on wells outside waterflood areas were not uncommon. Later studies (Bailey 1990) found that in the Vacuum Field, water was indeed flowing along distinct horizons within the Salado. Chemical and isotopic analyses confirmed that the brines were not natural to the Salado. Casing leaks were thought to be the most logical pathway into the Salado. Casing leaks and cement degradation are not uncommon in the highly saline environment (LaVenue 1991).

In the vicinity of WIPP, there are oil and gas resources. Much of the drilling for oil and gas has been delayed by the presence of potash. Nonetheless, there has been drilling for oil and gas in areas known to contain less than economic

quantities of potash. There is no question that waterflooding in the immediate vicinity of WIPP needs to be anticipated. First, the oil reservoirs in the area produce by solution gas drive (Broadhead and Speer 1993). Reservoirs which produce by solution gas drive are usually good candidates for waterflooding (Willhite 1986). Second, there is a waterflood underway in the Cabin Lake Field at the northwest corner of the WIPP Site. A nearby oil well, James A No. 2, has shown a good response with oil production increasing from less that 2,000 barrels per month to more than 4,000 barrels per month for that particular well. Third, there are eight waterfloods underway in the New Mexico portion of the Delaware Basin (Broadhead et al. 1995) and there is a history of waterflooding and enhanced oil recovery in the Texas portion of the Delaware Basin.

2.6.2 Presentation by Matthew Silva

The assurance requirements in the EPA Standards for the disposal of transuranic waste state that one should avoid areas with natural resources. The WIPP is not independent of the potash industry and the oil and gas industry, their schedules for resource recovery, and the problems associated with these industries. In the oil fields overlain by the Salado Formation, where we have experience with waterflooding, there is evidence of water escaping from the injection areas and migrating through the Salado. The Delaware Mountain Group, in the vicinity of the WIPP, is a strong candidate for future waterflooding.

The EPA standards for the disposal of transuranic wastes have assurance requirements. These assurance requirements are intended to accommodate the inherent uncertainty in calculating repository performance over the next 10,000 years. With respect to natural resources, the assurance requirements state that a site should avoid places where there has been mining for resources, where there is a reasonable expectation of exploration for scarce or easily accessible resources, where there is a significant concentration of any material that is not widely available from other sources.

The Known Potash Lease Area, as shown in Figure 2.6-1, is contained in an area roughly 30 miles by 30 miles. The 4 mile by 4 mile WIPP is located within the potash enclave. The first mining and second mining areas are shown. Potash has been commercially mined for 64 years - an area with a long history of mining. Potash in this area represents 57% of the nation's reserves and has consistently represented over 80% of the nation's domestic potash production - a relatively scarce resource. Oil and gas reserves are also found in this area - an easily accessible resource.

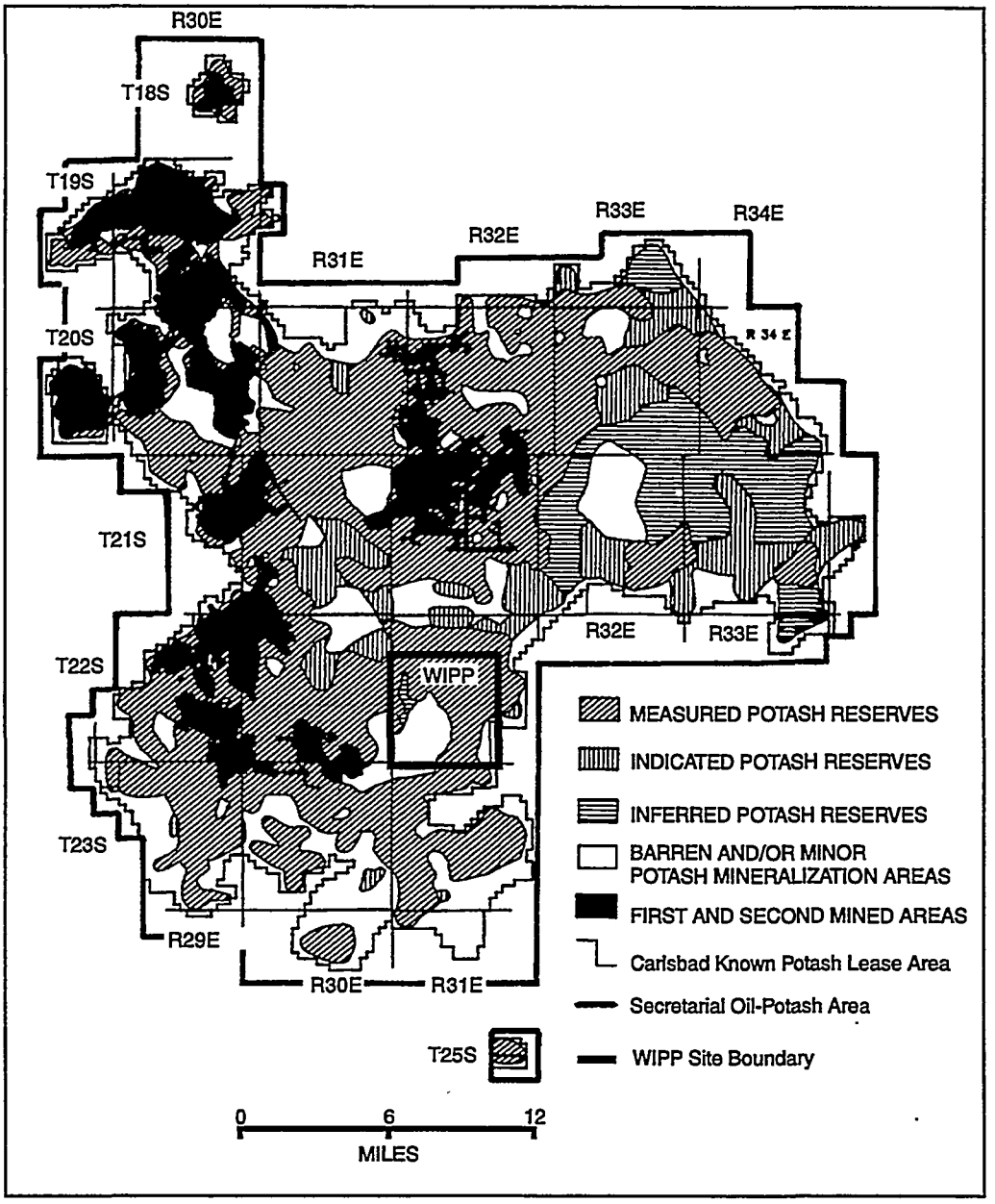


Figure 2.6-1. Potash resources (adapted from Olsen 1993).

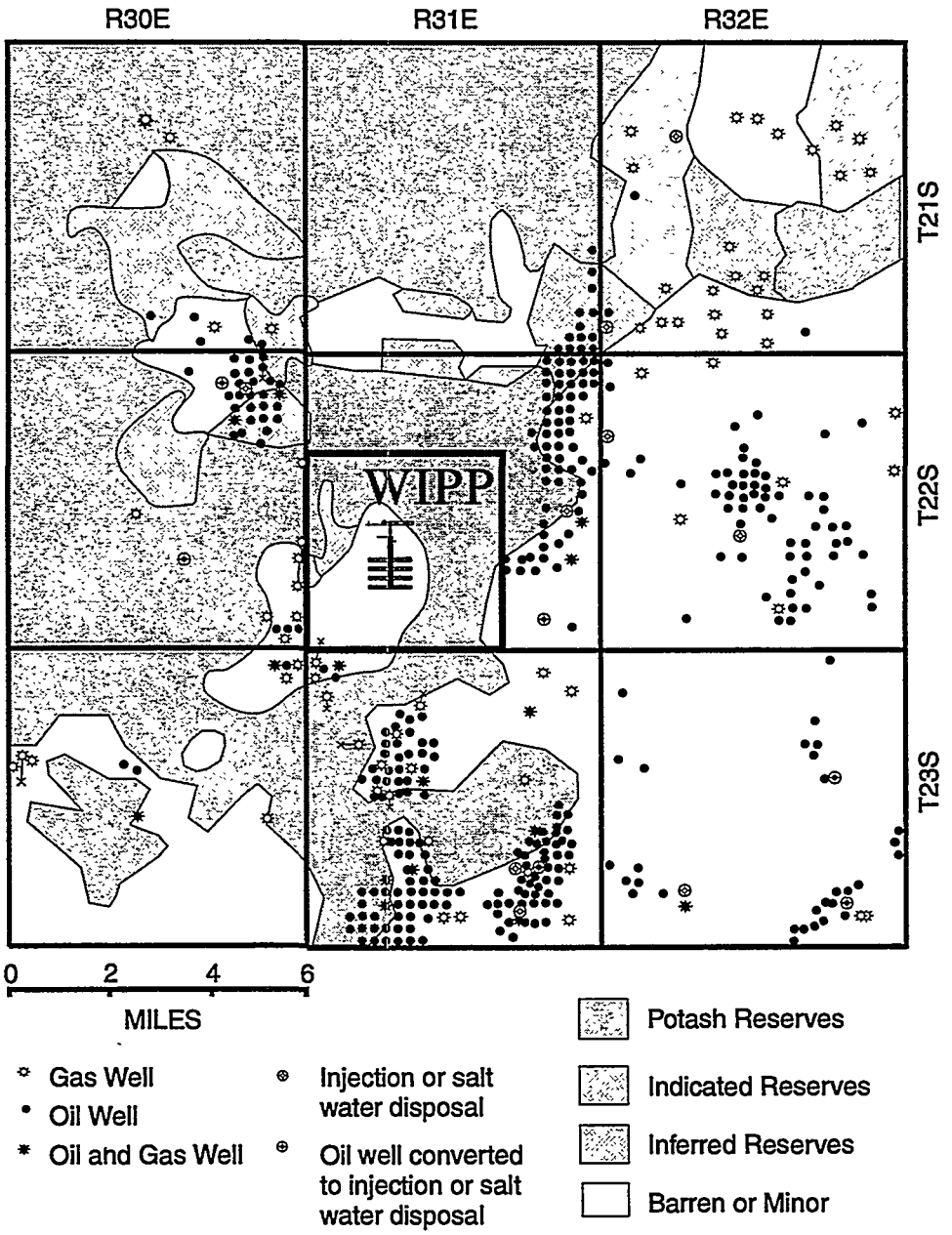


Figure 2.6-2. Oil and gas wells restricted from drilling through potash resources.

For the nine township area surrounding the WIPP, it is important to note that the current areal extent of the oil fields is constrained by the boundary of potash reserves and not the geographic limits of oil and gas.

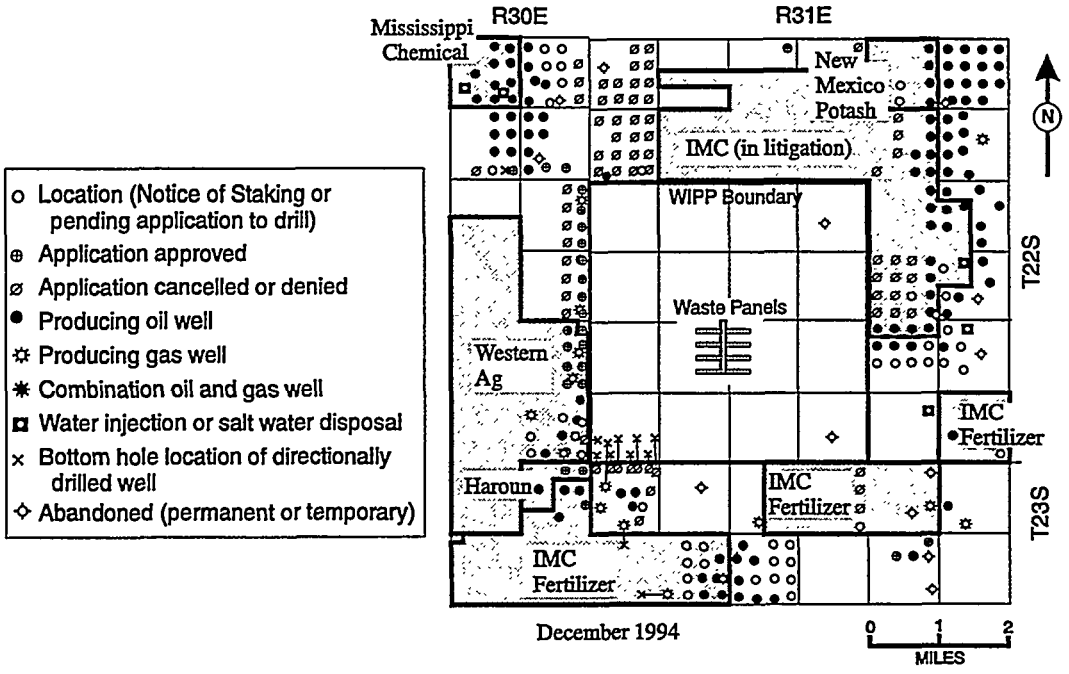


Figure 2.6-3. Resource activity and interest in the immediate vicinity of WIPP.

Will there be any more drilling near the WIPP boundary or is it restricted by the presence of potash reserves? Producing oil and gas wells and applications for permit to drill (APDs) within 2 miles of WIPP are shown in Figure 2.6-3. Applications include those that are pending, that have been cancelled, or that have been approved. Also shown are the active potash leases in the area. Oil and gas resource activities are restricted by the presence of potash. Further, it could be decades before drilling for oil and gas is allowed. Again, the limited number of existing oil and gas wells does not reflect the size of the oil fields, rather it reflects the presence of potash in an active potash leasing area.

Towards the southwest corner of the WIPP Site, the BLM has recently denied applications to slant drill eight wells to be completed within the WIPP Land Withdrawal Area. These applications have been denied for a couple of reasons, including the concerns about the injection of water.

A 1994 map from Midland Map Company indicates that Todd Federal #3 has been

plugged and abandoned. Also Rick Beauheim showed evidence this morning of rising water levels in H-9 up until 1993. The water levels started to decline and are now rising again. Somewhere about that time this well was apparently shut in.

The oil wells producing from the Delaware Mountain Group are very large water producers. That reflects interstitial water, not a large edge water drive. There are a number of salt water disposal wells throughout the area already in operation. The David Ross AIT Federal #1 is an oil well that was converted to a salt water disposal well. It's within a mile of the WIPP site boundary. It injects from 40,000 barrels to 120,000 barrels a month as salt water disposal. Other than state regulations, there are no extra requirements on this particular well.

To the west of the WIPP there is an injection well in the potash area less than a mile from the mining operation of Western Ag. In 1994, when Western Ag learned that this particular well was being proposed as a salt water disposal well for Bass Enterprises, Western Ag proposed 12 stipulations. The stipulations included an annual analysis of the chemical composition of the water and the hydrocarbons and of any hydrosulfide that was being injected into that well. The stipulations also specified maximum injection pressures. Further, Western Ag wished to be notified immediately of any problems with tubing failure. While the David Ross AIT Federal #1 is within a mile of the WIPP site, there are no special provisions for this well. Yet for the well within a mile of potash operations, Western Ag was concerned with water being injected out of zone.

New Mexico has extensive experience with waterfloods in areas overlain by the Salado Formation. Serious problems have been documented for the past 20 years. In 1976, Joe Ramey, as the Director of the New Mexico Oil Conservation Division, identified the problem of "numerous salt water flows in and around waterfloods in Lea County." Basically the water was escaping out of the injection zone, up into the Salado Formation and then moving through the salt section, collapsing oil field well casings. Five thousand to six thousand barrels of water

a day at 1,600 pounds per square inch pressure at the surface were not uncommon.

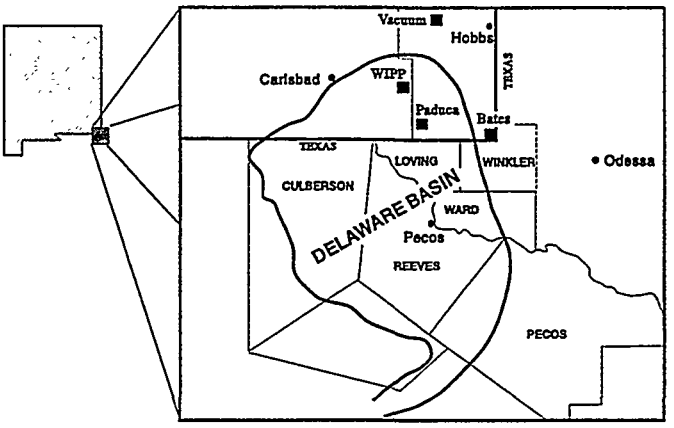


Figure 2.6-4. Delaware Basin.

In 1990, Jamie Bailey, a certified professional geologist and petroleum engineer for the New Mexico State Land Office, sent a memo to Marsh LaVenue on the observed water level rises in the Culebra aquifer during the 1988-1989 time frame. That memo cited the problems in the Vacuum Field waterfloods and the reports prepared by a committee of participating oil companies. The memo noted that waterflows occurred along 48 distinct horizons or interbeds within the Salado. Chemical and isotopic analysis confirmed that the brines were not natural to the Salado and these were injected brines. The memo concluded that failed casing was the most logical pathway into the Salado and observed that there were similar problems in other waterflood areas including the Eunice and Monument areas. Bailey identified a salt water disposal well, the Todd 26 Federal #3, as the most likely source of water to the Culebra aquifer based on the injection pressure history, the age of the particular well, and the location of the well.

There is more recent evidence of problems with waterflooding in New Mexico. The operator of the Bates Lease, Hartman, successfully demonstrated in court that water from the Rhodes/Yates Lease was being injected at high pressures and was migrating more than two miles to his lease. The Bates #1 was drilled in 1953. It was operated until 1988, at which time it was shut in. When it was drilled in 1953, there were no observed waterflows. The Bates #2 was drilled about one hundred feet to the east in January 1991. It experienced a very large salt water blowout. Two-hundred-ninety-eight truckloads of water had to be hauled away

and a pipeline was constructed to the water injection unit at the Leonard Field.

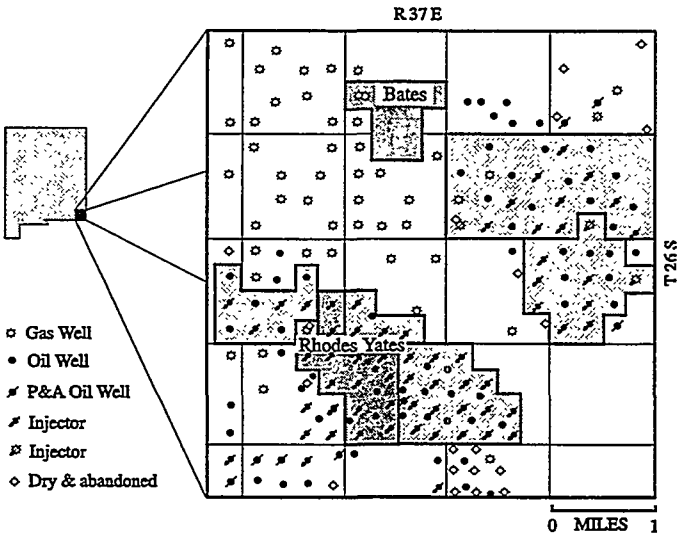


Figure 2.6-5. Bates Lease (Hartman), Rhodes Yates Waterflood (Texaco) and other nearby leases with injection wells.

Hartman argued that the Rhodes/Yates lease was the only water flood with an injection pressure gradient high enough to see the type of water pressure that was seen at the Bates Lease blowout. Hartman also argued that the waters were being injected higher than the rock fracture pressure of the interbeds of the Salado formation.

Are these wells in the area near WIPP waterflood candidates? The major Delaware Mountain Groups produce by solution gas drive (Broadhead and Speer 1993, 299). Solution-gas-drive reservoirs usually are good candidates for waterflooding (Willhite 1986, 3).

Adjacent to the WIPP Site Boundary, the No. 2 James A well responded favorably to waterflooding. This well is operated by Phillips, a major oil company, not a small operator. Initially, this well produced 4,000 barrels per month. As shown, production declined to

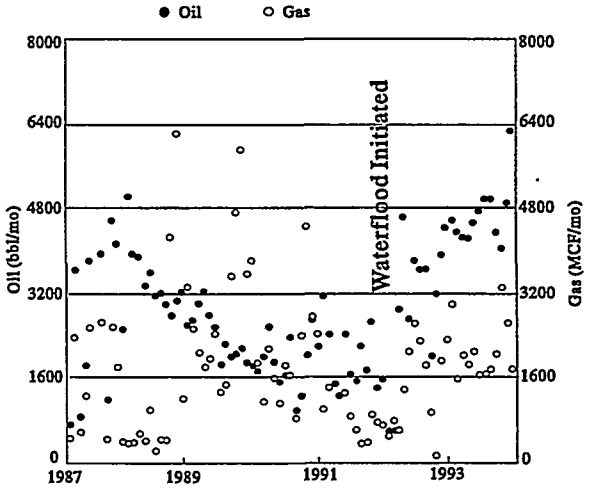


Figure 2.6-6. Response of No. 2 James A to waterflood.

less that 2,000 per month. The pressure maintenance waterflood was initiated with the conversion of one nearby well to waterflooding and later a second injection well. There was an immediate response, even to the one injector well. The oil production rate for the James #2A again exceeded 4,000 barrels per month.

Further, as noted by Broadhead, there are examples of successful waterfloods in the Delaware Basin. For example, the Paduca field which produces from the Delaware Mountain Group responded well to waterflooding as shown. A waterflood was initiated in 1968. Thus far primary production accounts for 8.6 million barrels cumulative production and waterflooding has produced an additional 5.2 million barrels. It is also worth noting that this Delaware Basin field has been in production for over 30 years and is still in production.

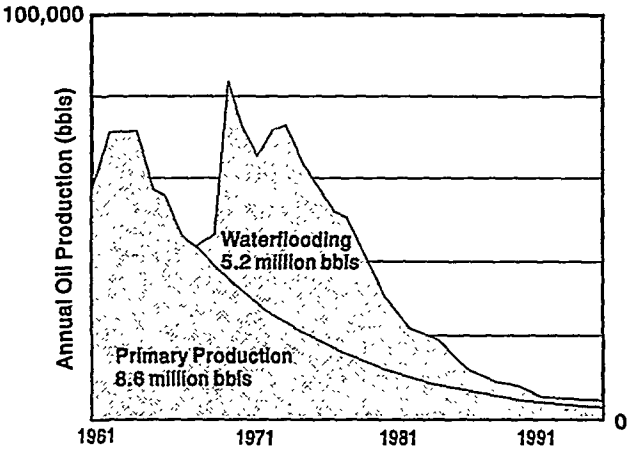


Figure 2.6-7. Paduca Oil Field Production.

2.6.2.1 Conclusions

The WIPP is sited in a mineral rich area and will be subject to the practices of the oil and gas industry and the potash industry. Drilling for oil and gas has been delayed primarily by the remaining presence of potash reserves. There is a history of waterflooding to improve oil recovery from producing fields throughout the Delaware Basin. There is also experience with water migrating out of the injection zone and into adjacent properties in the oil fields of southeast New Mexico. Near WIPP, there are a few new injection wells for the purposes of salt water disposal and waterflooding.

2.6.2.2 Questions:

Dan Stoelzel: Did you find any records of blowouts or casing collapse problems in offset producers. Did you see any of these type of incidences in your research?

Matthew Silva: I did not look in detail at the wells down there.

Dan Stoelzel: That is one thing I planned on doing. I just ran out of time. That would be an indicator that these disposal wells are indeed causing problems, you see it in offset wells both in the drilling phase and later in the production phase.

Matthew Silva: Certainly, part of the problem facing the project is that if you want to look at all of those, you have to look at each well on a case by case basis. It is a massive effort to try to understand that.

Wendell Weart: Something that is not directly related here, but I am curious that we now have such a proliferation of holes around the site which we did not have back around the late 70s and early 80s. Is there any information from those about encounters with brine reservoirs in the Castile?

Matthew Silva: Yes, we do have some information. About 2 years ago I did request from the various oil companies information on their water flows all which were in the Castile Formation around the WIPP site. About one third did respond with detailed records and another third did not respond at all. Some declined to provide that information.

Dan Stoelzel: Are you going to come forth with that information at some point?

Matthew Silva: As soon as I have time to put it together, I will.

Robert Neill: We will certainly share the information for the one third that did respond.[1] *****

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[1]That information was sent to Peter Swift on March 20, 1996.

2.7 Geological Features Across the Oil Fields of Southeast New Mexico and West Texas

Lokesh Chaturvedi

2.7.1 Synopsis

The Waste Isolation Pilot Plant (WIPP) is located in the northern part of the Delaware Basin. The Vacuum Field and the Bates Lease/Rhodes-Yates water flooding areas are situated in the shelf (backreef) areas, about 40 km northeast and 65 km southeast of WIPP respectively. Sratigraphically, the backreef equivalent of the oil producing upper Guadalupian Delaware Mountain Group Formations of Cherry Canyon and Bell Canyon, are the Artesia Group Formations of Grayburg, Queen, Seven Rivers, Yates and Tansill. San Andres limestone of the shelf is the stratigraphic equivalent of the lower Cherry Canyon Formation of the Delaware Basin. The Castile Formation is confined to the Delaware Basin only, but the Salado Formation extends more than 160 km beyond the margin of the Basin to the north and east into west Texas. In the southeast corner of New Mexico in the area of Rhodes-Yates waterflooding, the Salado Formation lies unconformably over the Artesia Group. Thus, a well penetrating through the Salado at the WIPP site would go through the Castile anhydrite and halite beds before entering the Bell Canyon Formation of the Delaware Mountain Group. At the Bates lease area, on the other hand, such a well enters the Tansill and the Yates Formations directly below the Salado. The vertical distance from the oil producing zones in the Cherry Canyon Formation surrounding the WIPP to the WIPP repository is approximately 1,200 to 1,800 m. In the backreef area, the distance between the Yates producing zones and the lower Salado is less, approximately 500 m. However, the Salado interbeds extend through the entire Salado from the Basin to the backreef and once pressurized fluids are injected into them, the Salado interbeds are expected to behave essentially the same way.

2.7.2 Presentation by Lokesh Chaturvedi

The point that Lori Dotson was making is that there is a difference in geology between the situation at the Bates lease and the situation at the WIPP Site. As stated in my synopsis, that difference is mainly in vertical distance. At the WIPP Site, it is the vertical distance between the Lower Salado and the Cherry Canyon or Brushy Canyon oil reservoirs. At the Bates lease it is the vertical distance between the gas producing Yates Formation and the level in the Salado of the salt water blowout in the Bates lease #2 borehole.

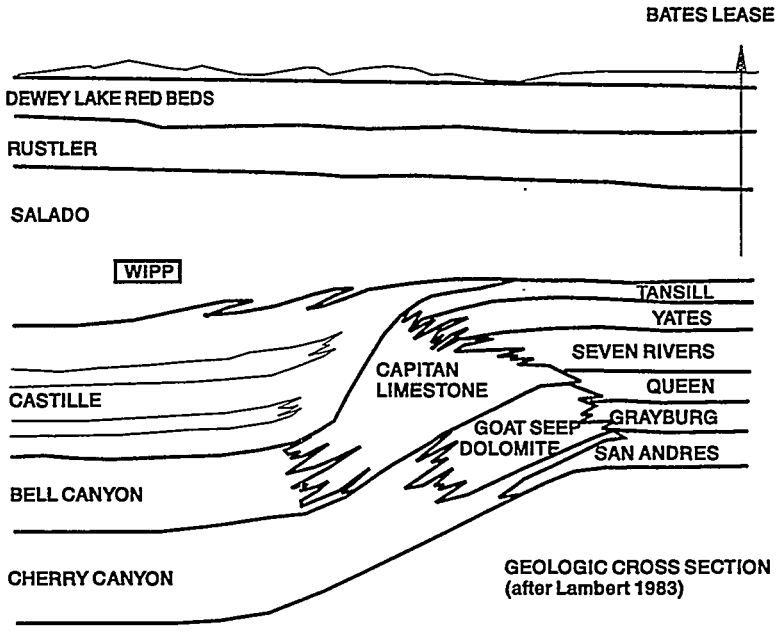


Figure 2.7-1. Geologic cross section at WIPP and Bates Lease (After Lambert 1983).

However, the main point of interest is that the Salado Formation is the formation that remains essentially the same across the reef. The thickness of the Salado decreases somewhat across the reef, but despite the forty mile distance between the WIPP and the Bates lease, the essential characteristics of the Salado, that of the presence of interbeds, remains the same. If the pressures are sufficient and the conditions are appropriate for water to leak out of the casing, water will be

injected into an interbed in the Salado or possibly into the water bearing zones such as the Culebra and Magenta of the Rustler Formation.

There may be a vertical distance but if the pressures are sufficient to cause injection of water into the Salado or Culebra, then it seems to me, that what happened at the Bates lease is quite likely to happen at the WIPP Site. The distance between the Texaco wells and the Bates lease #2 well was about two miles. If we accept, as Dennis Powers described, that there were no likely natural sources of such huge quantities of salt water, then most likely the source of water was the waterflooded area in the Texaco lease. If that is what we believe to be the case, then we know that such an effect can be felt more than two miles away. We know it can be felt two miles away. We don't know if it can be felt more than two miles away. Since the oil wells around the WIPP Site are about two miles away from the repository, regardless of the vertical distance from the Salado to the oil producing zones, I do not see a difference in the essential characteristics of the situation, which is the presence of the Salado Formation and its interbeds.

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2.8 Perspectives from WIPP Performance Assessment

Peter Swift and Rip Anderson
Sandia National Laboratories

2.8.1 Synopsis

Two main EPA regulations address the long-term (10,000-year) performance of the WIPP: 40 CFR 191 sets standards for releases of radioactivity from the disposal system; and 40 CFR 268.6 applies to long-term releases of hazardous constituents (e.g., volatile organic compounds and heavy metals) regulated under RCRA. 40 CFR 191 provides a regulatory definition of performance assessment (PA) that applies to the WIPP. It is "an analysis that: (1) Identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties caused by all significant processes and events." (40 CFR 191.12).

WIPP PA uses computational models to estimate cumulative radionuclide releases for selected scenarios. These scenarios are developed using a methodology which begins with establishing a comprehensive list of features, events, and processes (FEPs) which may affect the disposal system. These FEPs are then screened using four basic criteria: relevance, regulatory requirements, probability of occurrence, and consequence. Scenarios for system level modeling are constructed from those FEPs that remain following screening. To date, screening arguments are documented for approximately 800 of the 900 FEPs initially identified. Screening arguments remain to be developed or documented for many FEPs, including some related to oil and gas activities.

2.8.2 Presentation by Peter Swift

This is a brief overview of performance assessment methodology, more specifically, the development of scenarios for performance assessment. In an effort to address regulatory requirements, performance assessment calculates the long term performance of the repository for the next ten thousand years. There are two regulations of primary interest.

40 CFR Part 191 regulates the release of radioactivity from the site. It was promulgated in 1985, partially vacated by the court in 1987, and repromulgated in 1993. There are essentially three requirements:

- §191.13 limits the cumulative releases of radionuclides to the accessible environment for 10,000 years from essentially all causes.
- §191.15 limits the individual dose for "undisturbed performance" for 10,000 years. (Undisturbed is defined to exclude human intrusion).
- §191.24 requires protection of underground sources of drinking water for "undisturbed performance" for 10,000 years.

The first item, the cumulative release requirement, has been driving the performance assessment calculations.

The second regulation of interest, 40 CFR 268.6, implements RCRA for the long term. It limits the releases of hazardous constituents, such as VOCs, organics, and heavy metals, at the disposal unit boundary for 10,000 years of undisturbed performance.

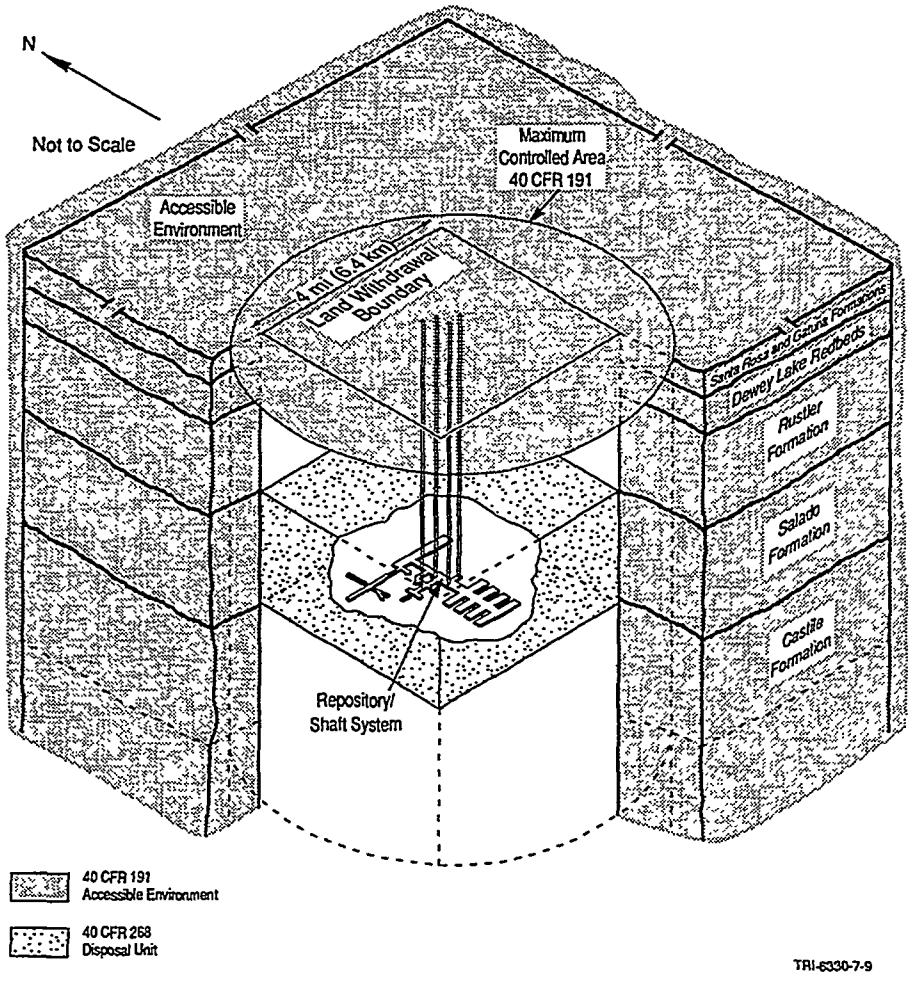


Figure 2.8-1. Accessible Environment and Disposal Unit Boundaries.

Shown here are the regulatory boundaries needed to assess performance measures. The repository is in the Salado Formation. It is underlain by the Castile Formation and the deeper hydrocarbon bearing units. The repository is overlain by the Rustler Formation which contains the Culebra, the formation in which Rick Beauheim observed the water level rises. Above that are the Dewey Lake Redbeds Formation and other relatively thin units such as the Santa Rosa Formation and the Gatuña Formation. The RCRA boundary, the RCRA disposal

unit, is defined to be the Salado Formation inside the four mile area. Releases are of interest at the top of the Salado Formation, at the bottom of the Salado Formation, or laterally to the 4 mile by 4 mile boundary.

For 40 CFR Part 191, the disposing unit is defined a little differently. The boundary of the controlled area is a cylinder extending up to the ground surface and downward as well. Radionuclide releases are of interest if radionuclides reach the ground surface or if they migrate laterally through marker beds in the Salado or through the permeable units in the overlying formations. We estimate the releases and sum the releases over 10,000 years. That is the performance measure that is compared to the EPA standard. The standard is probabilistic and regulates the probability of cumulative releases, not the magnitude of them, but the probability of releases of a certain magnitude.

For the WIPP 40 CFR 191 defines performance assessment. Performance assessment:

- identifies processes and events that might effect the disposal system,
- examines the effects on system performance, and
- estimates cumulative releases, including uncertainties, caused by all significant events and processes.

Performance assessment tries to capture this uncertainty by posing three questions.

1) What are the things that can happen in the future? (Scenarios or S_i)

2) What are the probabilities of those things?

3) What are the consequences of these things, if they should happen?

Risk is represented by an equation which contains an ordered set: 1) scenarios,

2) scenario probabilities, and 3) scenario consequences.

$$Risk = \{(S_i, pS_i, cS_i), i=1...nS\}$$

Performance assessment, for 40 CFR Part 191, is basically an attempt to solve the risk equation.

The flow diagram shows the performance assessment methodology. The process starts by characterizing the system. For the WIPP, there are 3 main parts, the site geology, the engineered facility, and the waste to be emplaced.

Performance assessment needs to develop scenarios. These are the things that might happen. Their probability needs to be estimated and a computational modeling system is needed to simulate these scenarios and estimate the consequences. A Monte Carlo consequence modeling system is used to perform multiple simulations using different sample parameter values, which describe the key parameters of the system. The simulations yield a set of outcomes that describes the uncertainty in the modeling system. The effort calculates the consequences for different scenarios, estimates the scenario probabilities, and gives a result that can be compared to the regulatory standards. If the exercise is a preliminary performance assessment, as has been the case since the late 1980s, then the process executes a sensitivity analysis that iterates through the system. The final iteration leads to the preparation of an application.

The first step to develop scenarios is to establish a comprehensive list of features, events, and processes (FEPs). Events and processes are identified in the regulations. A feature is neither an event nor a process, it simply may exist at the site. The WIPP FEP list was developed from nine independently derived FEP lists from different programs around the world. Some WIPP specific FEPs were added. The "Master List" contained approximately 900 FEPs. Some of these were not particularly relevant to WIPP. But in the interest of completeness they were included on the initial list. That list is in concept, an open list. If someone can think of it, and it has merit of any sort, it should be on that list.

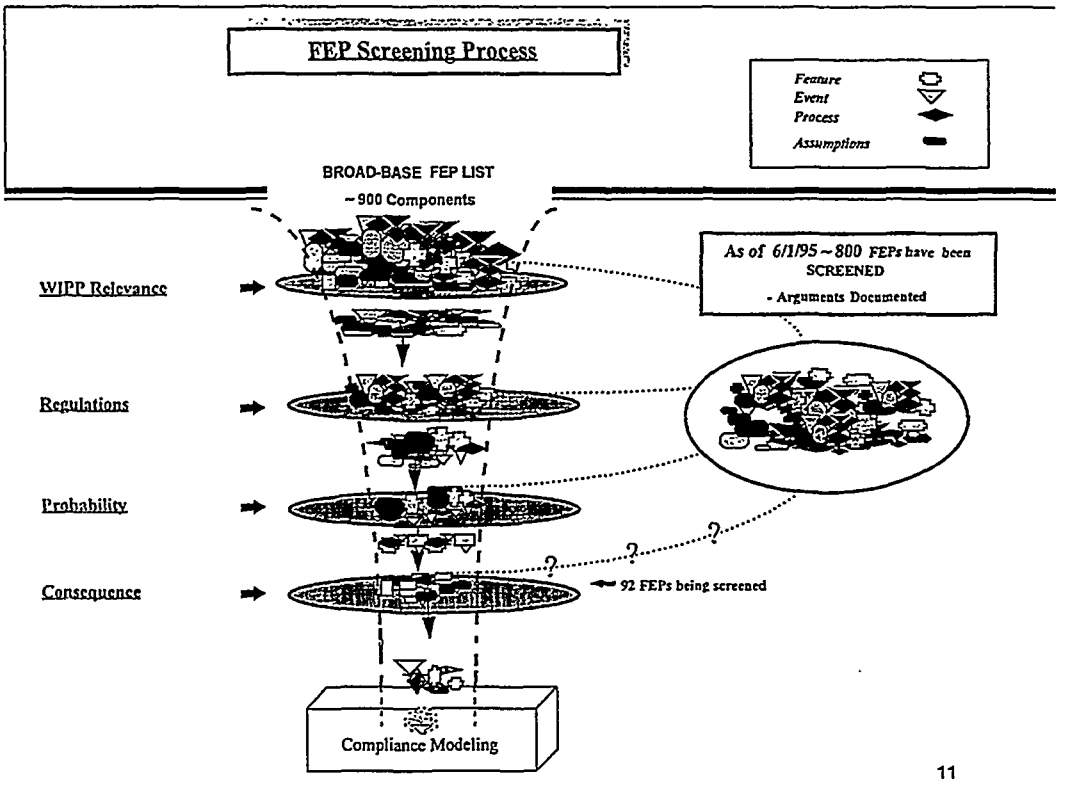


Figure 2.8-2. FEP Screening Process.

Next is the development of a screening argument. Screening does not mean screening out. It means screening either in or out of system level analysis. There are four screening criteria:

1) Relevancy

2) Regulation

3) Probability

4) Consequence

The first one is simply relevancy. For example, FEPs that relate to the disposal of high level waste or spent fuel are not relevant to WIPP.

The second is regulatory criteria. Two are important enough to mention here. First, the American regulatory period is limited to 10,000 years. FEPs beyond 10,000 years are not considered. Second, Appendix C of 40 CFR 191, specifies inadvertent and intermittent exploratory drilling as the most severe human intrusion scenario that should be considered.

The last two screening criteria are probability and consequence, assuming that the remaining FEPs, will be both relevant and included by the regulation. Then the process examines the probability of the FEP occurring and the consequences to the system. Regulation provides guidance for both of these. For probability, if a FEP can be shown to have less than one chance in 10,000 in 10,000 years, it need not be considered further. For consequence, if it can be shown that the performance measure would not be significantly changed by including the FEP in the analysis, then it need not be included. Of course, that presupposes there has been work done to support that consequence argument.

A schematic of the FEP screening process is shown. The order in which the first two screening criteria are applied is done on a case by case basis. At this time of the approximately 900 FEPs, work is ongoing for 92 of the remaining FEPs to determine their status.

2.8.2.1 Conclusions

Oil and gas related activities, e.g. waterflood injection, certainly are on our list along with other FEPs. Screening arguments remain to be developed and documented for several FEPs that are relevant here today, including waterflood injection. In other words, I don't have a screening argument today. I am not going to tell you what we decided to do about waterflood injection in terms of performance assessment modeling. In part, I am eager to hear what we learn here today and it would premature for us to come in with a conclusion already in hand. But I remind you that we will apply the three important criteria, probability, consequence, and the regulatory requirements.

2.8.2.2 Questions:

Robert Neill: In terms of the probabilities for screening, would you say that the probability of salt waterflooding or brine injection to improve oil recovery in the vicinity of WIPP is much, much less than 10^{-4} or much, much greater than 10^{-4}.

Peter Swift: At some locations the probability apparently is one, which is a good high number for a probability. I think it would be pointless of me to make the point any further. It depends on the location.

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2.9 Need for Water Flooding Scenario in WIPP Performance Assessment

William W.-L. Lee

2.9.1 Synopsis

After a series of presentations on the why, where and what-ifs of water-flooding, we come to the question of what does water-flooding mean for WIPP as a geologic repository of nuclear and mixed wastes. The USEPA requires performance assessments to include disruptive events or processes that are estimated to have more than one chance in 10,000 of occurring over 10,000 years. In the 1989, 1990, 1991 and 1992 WIPP performance assessments, the only disruptive event analyzed was human intrusion by drilling. WIPP has not analyzed a scenario specific to water-flooding.

In the most recent position paper on scenarios development, the DOE states:

> Fluid injection.
> Leakage from fluid injection wells associated with enhanced and improved oil and gas production, hydrocarbon storage, and disposal of unwanted liquids is retained for further consideration (p. 7-15).

Among the 124 FEPs being analyzed in side calculations, we find

- Interconnections within the controlled area for disturbed performance (to model effects of existing and future boreholes),
- Interconnections outside the controlled area for disturbed performance (to model effects of existing and future boreholes),
- Leakage from wells (from brine pockets, injection wells, fluids during drilling),
- Effects of mining inside or outside the controlled area,
- Connection to units beneath the repository,
- Current human activities outside the controlled area (e.g. hydrocarbon

extraction, fluid injection. (Anderson 1995).

While SNL/DOE has considered water-flooding, the impacts of water-flooding has not yet been analyzed in the compliance certification application.

2.9.2 Presentation by William W.-L. Lee

What does waterflooding mean and should it be incorporated into WIPP's performance assessment? Features, events, and processes (FEPs) that have a probability greater than 10^{-8} per year have to be considered in performance assessment. However, in the previous iterations of the WIPP performance assessment, the only disruptive event analyzed was human intrusion by drilling. And that is an important qualification.

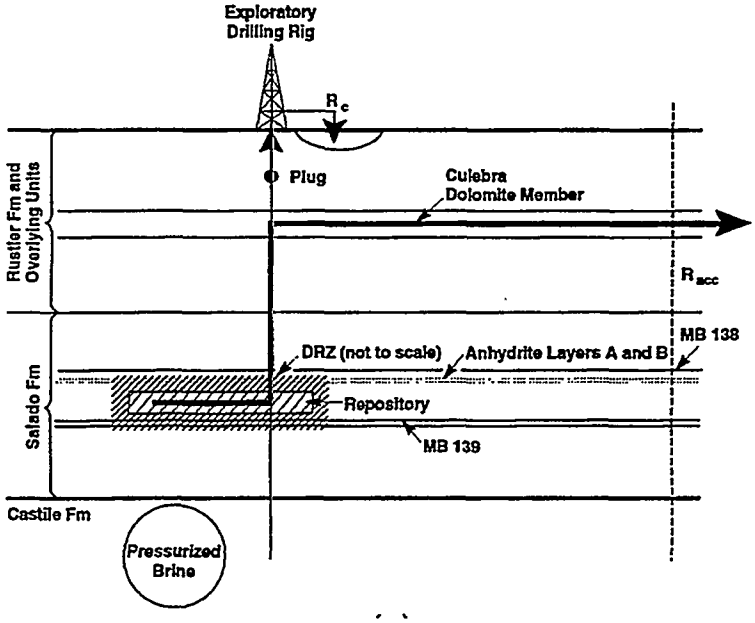


Figure 2.9-1. E2 Scenario

In the spirit of reviewing old work, I will show you the scenarios that were actually analyzed in the 1992 Performance Assessment. There was the E2 scenario in which a repository is pressurized with brine that flowed in from the Salado Formation, a driller hits the repository, and the pressurized waste moves up the well bore. There is a magic plug that diverts the material into the Culebra Dolomite. Compliance is measured at the accessible environment.

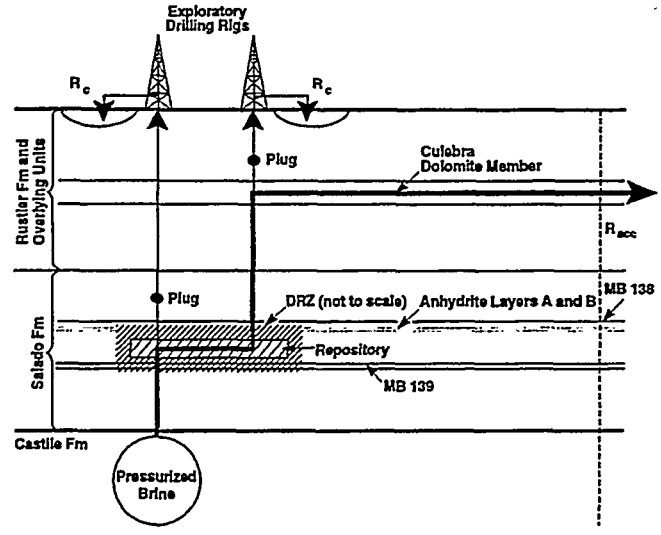


Figure 2.9-2. E1E2 Scenario.

In the E1E2 scenario, a driller first penetrates through the repository into a brine reservoir in the Castile Formation and thus floods the repository. A plug is put in place and there is now a brine pressurized repository. The E1 scenario is then superimposed on the E2 scenario.

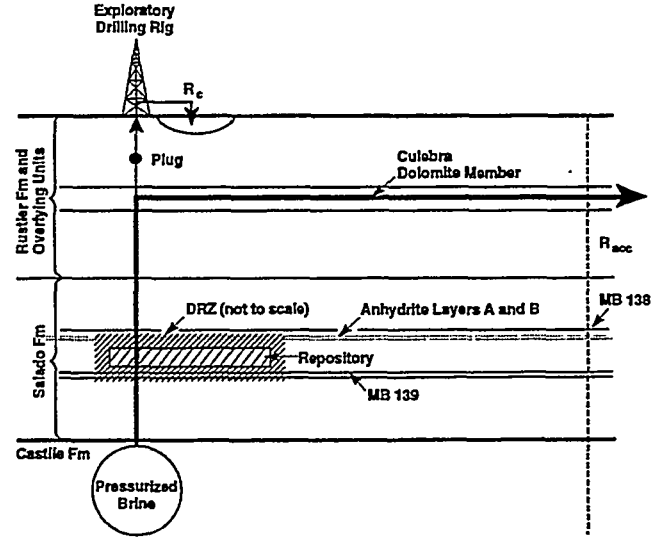


Figure 2.9-3. E1 Scenario.

The other possible scenario that was not analyzed by the 1992 PA was the E1 scenario which is the first half of the E1E2 scenario. The rationale given was that it is dominated by the E1E2 scenario although I believe Sandia has had some second thoughts about it.

Peter Swift just explained the process of screening FEPs. Starting with 900, two months ago there were 124 left. These are the ones related to waterflooding that are left.

- Interconnection within the control zone for disturbed performance and interconnection outside the disturbed performance.
- Leakage from wells including injection wells.
- Effects of mining inside or outside the control area.
- Connection to units below the repository.
- Human activity including fluid injection.

We have been told that Sandia National Laboratories is grinding away on side calculations to provide screening arguments for these FEPs. We await the results of these calculations.

The bottom line is this. Should the impact of potential waterflooding be in the current performance assessments and in particular, the draft application?

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END OF WORKSHOP PRESENTATIONS

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3. ANALYSES OF FLUID INJECTION ISSUES

Potential impact of fluid injection on the WIPP repository is analyzed in this chapter. The analysis uses the information presented at the workshop and that available in the literature and the public record.

As Chuck Byrum (EPA) noted in the afternoon discussion, waterflood and salt water disposal are two different processes regulated in different ways, designed in different ways, and the ultimate effects of each may be quite different. Kreitler et al. (1994, 4) described the difference between these two water injection activities. In waterflood projects, the presence of adjacent producing wells limits the extent of repressurization around the injectors. In contrast, salt water disposal wells are not used to increase oil production. Hence, brine may not always be injected into depressurized producing reservoirs. Initial fluid pressures in the disposal reservoirs may be hydrostatic, leading to overpressured conditions and upward fluid flow potentials. This analysis attempts to preserve the distinction between these two processes.

3.1 Salt Water Disposal

In his presentation, Beauheim showed data which led to his inescapable conclusion that a discreet human activity, most likely an injection well, caused the abrupt 1988 water level rise in wells south of the WIPP Site. Based on his own investigation, LaVenue (1991) also suggested the possibility of leakage from either a producing oil and gas well or a salt water disposal well in the area. Further, LaVenue (1991) speculated on the potential impact of a leaking well on the performance assessment calculations:

> If the recharge source is related to oil and gas wells in the area, it is not difficult to imagine significant increases and/or decreases in the water levels in the future as a result of additional recharge or discharge from oil and gas wells. Fortunately, there are almost no oil and gas wells within the

> WIPP-site boundary. Therefore, if wells are going to leak and have an impact upon the flow field, there is a higher probability that those wells will be located down-gradient or south of the WIPP site. Recharge from oil and gas wells south of the site should flatten the hydraulic gradient which would slightly increase ground-water travel time. If discharges from the Culebra occurs through a leaking oil or gas well south of the site, the hydraulic gradient would be slightly increased and the ground-water travel time would decrease (LaVenue 1991, 10-11).

In his presentation, Beauheim noted that higher potentiometric head in the Culebra in the southern part of the WIPP and south of the WIPP would flatten the hydraulic gradient and increase travel time. But he also emphasized that a change in gradient would not make a difference to the calculated performance assessment because of the relatively short life of such an injection activity. However, could a leaking injection well east, north, or northeast of the WIPP force large volumes of brine into the Culebra and significantly increase the gradient and reduce travel time? There are several new oil wells also producing large quantities of brine from the Delaware Mountain Group. To handle that waste brine, there are new salt water disposal wells operating just east of the WIPP Site. Wells are likely to be drilled to the north of WIPP when the area is open for drilling. The effect of higher heads in the Culebra in the north and east of the WIPP site should be analyzed in performance assessment.

3.1.1 Fluid Injection in the Culebra - *Bounded by Climate Change*

At the EEG workshop, Rip Anderson (SNL) acknowledged that the performance assessment effort, to date, has not specifically addressed fluid injection but that climate change would be in the final calculations. He maintained, however, that climate change assumption would bound any waterflooding scenarios because the climate change scenario takes the water table to the surface and that is the maximum possible water pressure. Anderson also stated that the presence of a

Castile brine pocket for the human intrusion scenario would cover any remaining concerns about waterflooding.

The 1995 DOE draft application to EPA (U.S. DOE 1995, Section 6.4.11) discusses climate change noting that the hydraulic head in the Culebra is raised to the land surface elevation along the northern boundary of the Culebra while the head remains fixed along the domains of the southern boundary. No results were presented. Rather, the draft document notes that the effect of climate change on groundwater flow is the subject of a current study.

3.1.2 Fluid Injection in the Culebra - *Not Bounded by Climate Change*

David Back (SC&A) questioned the DOE position that surface recharge bounded the impact of water level fluctuations in the Culebra. Back noted that the PA modeling assumed that the recharge would occur some miles to the northwest of the WIPP Site at the edge of the regional model. He pointed out that water from this recharge location would not pass through the WIPP site. Modeled this way, the water would flow south, through the higher transmissivity zone, straight to the assumed discharge area in Nash Draw, which is also west of the WIPP Site. However, if recharge occurred along the eastern edge of the WIPP, Back maintained that there would be an increase in the gradient, hence an increase in the flow rate through the Culebra over the WIPP.

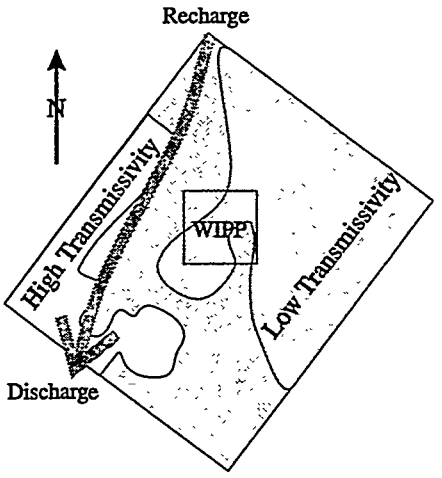


Figure 3-1. WIPP and Regional Flow Model for Culebra. Figure prepared by M.K. Silva.

3.1.3 Culebra Hydraulic Head Limited to Surface

Peter Swift (SNL) maintained that it is unlikely for a failed injection well to cause

pressures in the Culebra that are above the head at the ground surface. Data that support his position include the 181 pressurized water flows logged into the NMOCD Hobbs call-in log (November 1978 to May 1994) for southeastern New Mexico and the eight additional waterflows identified by Van Kirk (1994). Waterflows appear to be largely confined to the Salado and other deeper formations. There does not appear to be any artesian flow from the overlying aquifers such as the Culebra.

The notion of surface limited hydraulic head can not apply to the Salado. In the Vacuum Field, waterfloods exerted sufficient pressure to collapse well casings and pressures as high as 1600 psi were measured at the surface outside of waterflood areas (Ramey 1976). As mentioned by Lokesh Chaturvedi and discussed by Dennis Powers, the 1991 Salado salt water blowout at Hartman's Bates Lease was pressurized far above the surface hydraulic head as Hartman inadvertently discovered.

3.1.4 Brine Flow into Overlying Aquifers

Citing information from Dan Stoelzel, Rip Anderson made the following two points. First, a difference occurs only if water enters the Salado and the repository. Second, water escaping lower injection zones would flow past the Salado and would flow into the more permeable Culebra. Dan Stoelzel also suggested the reason injected water in the Vacuum Field did not come to the surface was because it was potentially going into the Ogallala, which is very permeable near the surface. The mechanism postulated by Anderson and Stoelzel raises interesting questions. At the Vacuum Field, or in other parts of New Mexico, or in other parts of the nation, has there been contamination of overlying aquifers, such as the Ogallala, as a result of oil field waterflooding? Is WIPP relying on contamination of an overlying aquifer by oil field waste brine as an acceptable alternative to flooding the Salado?

Some information supports the notion of water from oil field operations contaminating overlying aquifers. The U.S. Government Accounting Office (GAO) published a 1989 report entitled "Drinking Water Safeguards Are Not Preventing Contamination From Injected Oil and Gas Wastes." Class II injection wells are used to dispose of brine produced with oil and gas or to reinject these fluids to enhance oil recovery. Although the full extent of the problem was unknown in 1989, EPA was aware of 23 cases in which drinking water was contaminated by Class II injection wells. For the 23 confirmed cases of contamination, there were three principal causes. Five cases resulted from leaks in the casing of the injection well, nine resulted from migration through nearby improperly abandoned wells, and nine resulted from injection into the underground drinking water (U.S. GAO 1989).

One case of confirmed contamination occurred in New Mexico. During the 1970s, 20 million gallons of water leaked from a Texaco disposal well in Lea County, New Mexico into portions of the Ogallala aquifer, an underground source of drinking water. Some of the brine migrated into a rancher's irrigation well, damaged his crop and, according to the rancher, ultimately caused the foreclosure of his farm property. On the basis of the results of a pressure test, the rancher successfully sued Texaco in 1977 for damages (U.S. GAO 1989, 25).[9]

In the 1970s, potential contamination of the Ogallala near various waterfloods in Lea County was of concern to the New Mexico Oil Conservation Division (Ramey 1976). After years of study, the Vacuum Field Salt Water Flow Committee [a committee of oil company representatives] indicated flow was confined to the top of the Tansil and the bottom of the Rustler (Bailey 1990), thus isolating the problem of flow largely to the Salado. Bailey's spot checking old oil well drilling

[9] Texaco has since repaired the well and is now operating in compliance with Underground Injection Control although Texaco was not required to clean up the aquifer (U.S. GAO 1989, 25).

records indicated water flow drilling problems and numerous casing leak repairs in the Dewey Lake Red Beds and the Rustler in addition to the Salado (Bailey 1990).

3.1.5 Pressurized Brine Injection into the Salado

If there was salt water flow into the Ogallala at the Vacuum Field, as suggested by Dan Stoelzel, and into the Dewey Lake Red Beds and Rustler as indicated by Bailey (1990), can the performance assessment assume that overlying aquifers will serve as a relief valve for leaking wells in the WIPP vicinity, thus protecting the Salado, as suggested by Anderson and Stoelzel? It appears not. Despite the presence of overlying aquifers at the Vacuum Field, injected salt water exerted sufficient pressure to collapse well casings at the Salado horizon (Ramey 1976; LaVenue 1991). Similar observations of water flow through the Salado have been made in other oil fields with a history of waterflooding, including the oil fields near Oil Center, Monument, Eunice (Bailey 1990) and Jal (Hartman 1993).

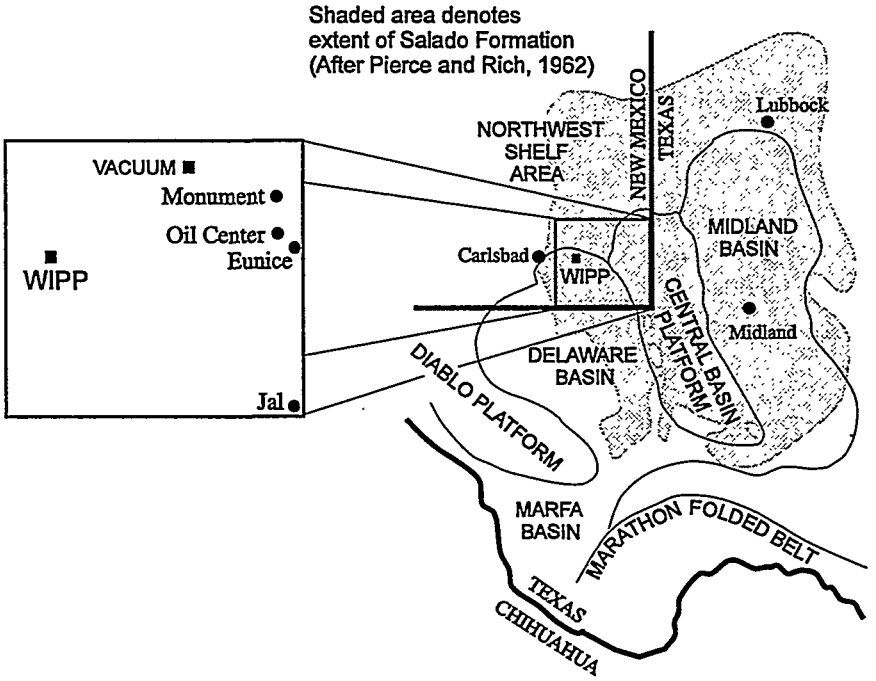


Figure 3-2. Areas overlain by Salado Formation.

Gallegos and Condon (1994) argued that the 189 water flows throughout District One of southeast New Mexico strongly correlated with waterflooding activities. These flows were in the Salado or at depths much greater than the overlying aquifers, strongly suggesting no relief mechanism. In light of this information, can the performance assessment defend the notion that brine escaping from an oil field waterflood or salt water disposal well will preferentially migrate into an overlying aquifer?

3.1.6 Devon Energy's Todd 26 Federal #3

As to the salt water injection well south of the WIPP Site, Dan Stoelzel commented that this well was probably responsible for the water level rises observed in H-9 (see Stoelzel's presentation). His conclusion was based on the schematic of the well completion. The well was originally completed in 1971 as a test well and immediately converted to a salt water disposal well. There is no salt isolation casing and it is an open hole completion similar to that of the Rhodes/Yates Field or the Vacuum Field. He commented that the well is now plugged and abandoned. Matthew Silva's reading of a commercial map also suggested that the well was abandoned.

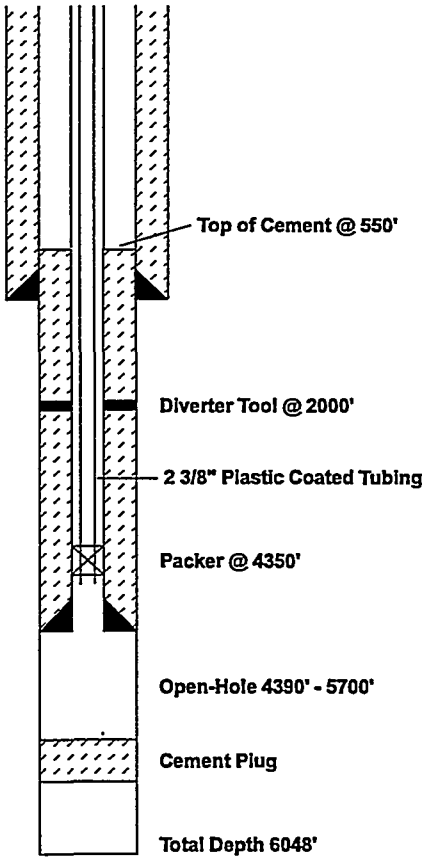


Figure 3-3. Texas Americal Oil Corporation Todd 26 Federal No. 3 Water Disposal Well (After Stoelzel).

It appears that the well was not plugged and abandoned and is still in service (Horsman 1995). The well is injecting into the Bell Canyon Formation, which is below the WIPP horizon. A comparison of the injection history at this well and

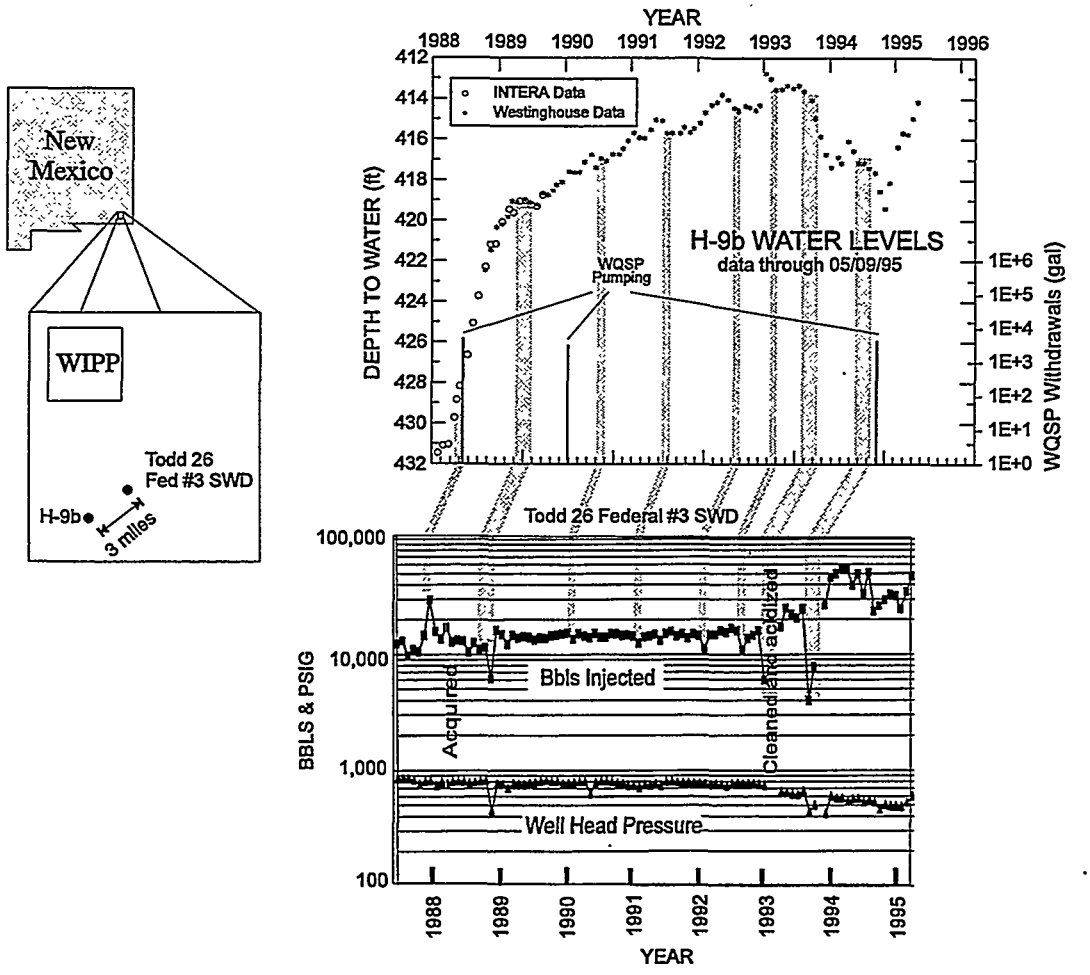


Figure 3-4. Todd 26 Federal #3 well injection data (Horsman 1995) and H-9 water level rises presented by Beauheim.

the water level rises at H-9 strongly suggests communication between the injection horizon, which is below the WIPP horizon, and the Culebra Dolomite, which is an aquifer above the WIPP horizon. There is more than 3,000 feet (980 m) of vertical separation between the horizons and approximately 3 miles (5 km) of horizontal separation between the wells.

Figure 3-4 strongly suggests a delayed response at well H-9 to injection events at the Todd 26 Federal #3. As noted in Richard Beauheim's presentation, the depth to water at well H-9 was essentially constant at 431 to 432 feet (141 m) for five

years prior to April 1988. An increase in the injection rate from 10,000 barrels per month to 30,000 barrels per month in January 1988 corresponds with the observed water level rise at H-9, which began in April 1988. This increase in injection is the event mentioned by LaVenue (1991) as potentially causing a tubing failure. Seven subsequent reductions in injection at the salt water disposal well rate are followed by corresponding water level declines at the monitoring well. In January 1993, injection operation ceased for two months. The water level at H-9 fell to levels not seen since 1990. After 1993, there appears to be either a delay in the response or perhaps a response to other injection wells in the area. It is worth noting that two other salt water injection wells began operating in the same general vicinity as Todd 26 Federal #3; Todd 26 Federal #2 SWD in January 1993 and Todd 36 Federal #1 in September 1994 (Horsman 1995).

The observations invite the obvious question. Are there problems with the Todd 26 Federal #3 well as suggested by Bailey (1990), by LaVenue (1991), and in Stoelzel's discussion of the well completion? Subsequent to the EEG workshop, the well passed a scheduled, routine, mechanical integrity test on August 16, 1995. In response to a request from the U.S. EPA (Catanach 1996a), the New Mexico Oil Conservation Division had the well subjected to a radioactive tracer test on November 13, 1995, to determine if injected fluid is migrating upward through channels in the vicinity of the wellbore (LeMay 1995a).

> The results of the tracer surveys (analysis attached) indicate no channeling behind the production casing and no vertical migration of fluid from the injection interval. It is the opinion of the Division that no further testing of these wells [Todd 26 Federal #3 and David Ross AIT Federal #1] is necessary (Catanach 1996b).

Assuming the tests were conclusive with respect to the integrity of the tubing, the casing, and the cement, the results of the test raise more questions. Are there vertical conduits in the vicinity such as improperly abandoned wells and/or wells

with deficient casing or cementing? Or are there vertical fractures in the vicinity that are not detectable by a radioactive survey of the wellbore area? Is there indeed a correlation between water injected and water level rises as suggested by the injection and water level rise data? If so, how does water injected more than 4,000 feet (1300 m) below the surface get through thousands of feet of two relatively impermeable bedded salt formations, the Castile and the Salado, and end up in an overlying aquifer? Is bedded salt, in the vicinity of water injection activities and abandoned oil and gas wells, truly a geologic barrier?

3.1.7 Yates' David Ross AIT Federal #1

Although there are several salt water injection wells in the area, this is the only salt water injection well operating within one mile of the WIPP Site at this time. During the afternoon deliberations, George Dials (DOE) raised the issue of institutional control noting that DOE has the opportunity to take credit for institutional control for up to 100 years and the DOE intends to maintain institutional control for at least 100 years.

As the only salt water disposal well operating within one mile of the WIPP site, the record on Yates' David Ross AIT Federal #1 provides interesting observations about institutional control.

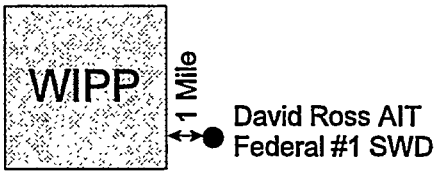


Figure 3-5. Location of David Ross AIT Federal #1 Salt Water Disposal Well.

First, the BLM received an application for permit to drill an oil well on January 17, 1991. The BLM approved the application on January 31, 1991, without obtaining a review from the DOE despite the October 26, 1990, Memorandum of Understanding (MOU) requiring it. The approval of this well completely bypassed "the controls that are crucial to protecting the site from inadvertent exploration" (Arthur 1992; Silva 1994, 46). The policy has been in place since 1983:

As an additional measure, the BLM will notify the DOE of any requests for resource recovery permits within one mile of the WIPP Site boundary so that the DOE will be aware of resource recovery activities near the Site (McGough 1983).

Second, when the well failed to produce much oil from the perforated zone, the operator proposed to convert it to a salt water disposal well. There was an objection, but it was not raised by the DOE. Mitchell Energy expressed concern about the loss of oil reserves as a result of brine injection into potential oil producing horizons and wished to limit injection pressures (Stephenson 1991). An agreement was reached between the two oil companies (Kellahin 1991) and the conversion to a salt water disposal well was approved on May 22, 1991 (LeMay 1991). The well was to be equipped to operate at a maximum pressure of 900 psi (LeMay 1991). Over the next several months, the well casing was perforated and zones within the approved interval were acidized and fractured until sufficient water could be injected (Goodlett 1991a, 1991b, 1991c, 1991d, 1991e, 1991f).

Third, the DOE continued to list this as an oil and gas well (Arthur 1993a, 1993b) and appeared unaware that this was a salt water disposal well despite the absence of oil production equipment, the presence of a battery of salt water tanks, the presence of a sign labeled "SWD," the "SWD" label on the BLM map, and BLM and NMOCD records clearly stating "salt water disposal well" (Silva 1994, 55-56; Kehrman 1995, 254, lines 18-20).

Fourth, the DOE, the EPA, the BLM, and others rely on the New Mexico Oil Conservation Division to ensure that water is not injected above the approved injection pressure. An examination of the public record (NMOCD 1996) indicates that the David Ross AIT Federal #1 was operated 20 psi above the approved injection pressure of 900 psi (LeMay 1991) during the months of September and October 1995, yet the well had been equipped so that it would not operate above 900 psi.

Government ownership, regulation, and public records are components of institutional control. The observations above raise questions about how much credit can be allowed for institutional control of the resource recovery activities in the vicinity of the WIPP site.

There does not appear to be an identifiable relationship between the injection of brine at the David Ross AIT Federal #1 and the water level rises at the P-18 well. The material presented by Rick Beauheim and the arguments submitted by Fant (1995) strongly suggest that there is insufficient evidence of direct communication between these wells. Fant (1995) makes a compelling argument that the P-18 well, which was originally drilled as a potash corehole, may be providing a connection between the Culebra and Magenta Formations. As noted by Rick Beauheim, there may be a problem in the P-18 well with the bridge plug, the cement job, or the cement bond.

3.2 Water Flooding

The problems with waterflooding in oil fields under the Salado Formation, or more specifically, the migration of injected water through the Salado Formation to adjacent properties, is well documented (Ramey 1976; Bailey 1990; LaVenue 1991; Hartman 1993, Herrera 1995). At the EEG workshop, Dan Stoelzel and Lori Dotson of Sandia National Laboratories maintained that at WIPP, migration of water through the interbeds of the Salado, such as occurred at the Rhodes Yates Field and the Vacuum Field, was highly unlikely for a variety of reasons. These included differences in geology, changes in oil-well completion practices from the 1940's, and improved reservoir management. Stoelzel and Dotson argued greater vertical separation at WIPP will protect the repository. They also argued that large scale water flooding near the WIPP is unlikely because the oil pools near WIPP are characterized by thin net pay zones, low permeabilities, high reducible water saturations and high residual oil saturations. They also maintained that oil

production by primary and secondary recovery would require less than ten years each. These issues are discussed below.

3.2.1 Differences in Geology

With respect to water injection, Dan Stoelzel and Lori Dotson cited vertical separation as an additional protection for the WIPP. Their arguments rely on the observation that oil production near the WIPP occurs at depths greater than 7,000 feet (2300 m) or about 5,000 feet (1640 m) below the repository horizon. Oil production at the Vacuum Field occurs at approximately 4,500 feet (1480 m) and at Rhodes Yates at 3,000 feet (980 m). In their abstract, Dotson and Stoelzel state there was only a couple of hundred feet ~(65 m) of vertical separation between the Salado Formation and the waterflood injection zone at Rhodes-Yates. They also noted that the Castile Formation is missing at the Vacuum Field and the Rhodes Yates Field.

However, as noted by Lokesh Chaturvedi, there is one geologic feature common to the areas on either side of the reef. The Salado interbeds extend through the entire Salado across the Delaware Basin and over the backreef. Lokesh Chaturvedi maintained that once pressurized fluids are injected into the Salado interbeds at WIPP, the interbeds will behave essentially the same way as Salado interbeds at other locations.

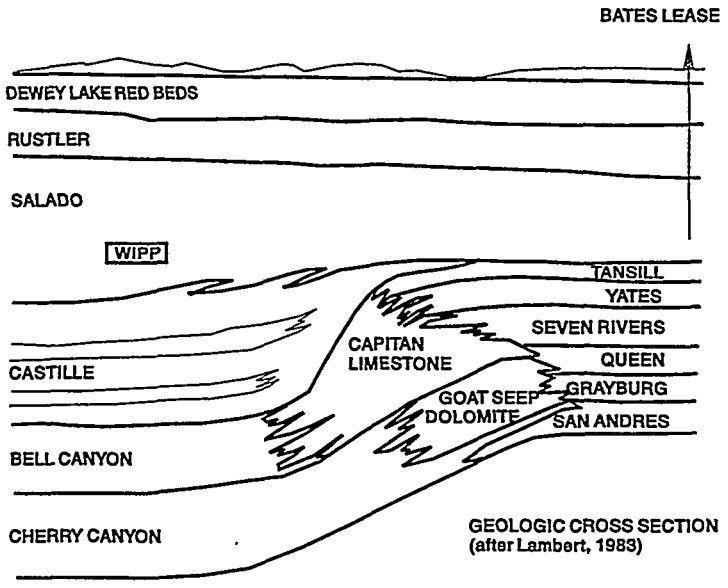


Figure 3-6. Continuity of Salado Formation.

In the afternoon deliberations, Dan Stoelzel and Lori Dotson offered opinions which contradicted the notion that vertical distance would protect the repository from communication with the deeper injection zones. For example, Dan Stoelzel maintained that the most likely source of water level rises in the Culebra at the H-9 well was the Todd 26 Federal #3 salt water disposal well. Matthew Silva observed that the salt water disposal well was injecting fluid in the interval from 4,400 to 5,700 feet (1440 m to 1870 m) below the surface. The water would have to migrate vertically 3,500 feet (1150 m) through the Castile and Salado to the overlying Culebra. That observation undermines Stoelzel and Dotson's position that such water migration would not occur because of about 3,000-5,000 feet (980 to 1640 m) vertical distance between the oil producing Delaware Mountain Group and the WIPP repository, or the overlying aquifers.

Lori Dotson commented that Silva's argument relied on the assumption that the water was leaking upward from the injection interval of 4,400 to 5,700 feet (1440 m to 1870 m). She maintained that the water could have been leaking from anywhere along the casing because that was a poorly designed injection well. Citing Stoelzel's earlier comments, Lori Dotson further commented that even if disposal brine was moving along the casing, it would take the path of least resistance and move into the Culebra. It would be easier for such water to enter the Culebra aquifer and not the Salado Formation. In bypassing the Castile and Salado Formations and flowing into the overlying aquifer, the oil field brine would not have an effect on performance assessment. But this explanation entirely undermines the "greater vertical distance" argument.

3.2.2 Livingston Ridge Delaware Waterflood

Dan Stoelzel maintained that small companies typically have shallow pockets and are unlikely to initiate water injection because of the cost to convert a production well into an injection well. It is worth noting that the active operators within two

miles of the WIPP Site include Phillips, Texaco, Pogo, Yates, Enron, Bass, Mitchell Energy, and Santa Fe Energy.

On October 10, 1995, Pogo Producing submitted an application to begin a pilot pressure maintenance project[10] (Bruce 1995a). Pogo intends to inject water into the Brushy Canyon of the Livingston Ridge-Delaware Pool through a well approximately one mile east of the WIPP Site Boundary. The injection interval is from 7,050 feet to 7,068 feet (2313 m to 2319 m) for a total injection interval of 18 feet (6 m), a relatively narrow zone of perforations. The original spacing of the wells has not been changed. A production well is to be converted into an injection well. Pogo plans to inject 365,000 barrels of water per year. The operator of the pressure maintenance project anticipates that three wells will see increased oil production, Neff Federal #1 and #2 in Section 25 and Neff Federal #1 in Section 26 (LeMay 1995b, 3). The operator also requested an administrative procedure to expand the pressure maintenance project, and at a later date, to include additional lands and/or injection wells (LeMay 1995b, 4). The WIPP can anticipate waterflooding of the Livingston Ridge/Lost Tank Delaware by independent operators on yet to be determined patterns.

3.2.3 Likelihood of Large Scale Waterflooding

Lori Dotson maintained that the oil pools near WIPP are relatively small when compared to the Vacuum Field and the Rhodes Yates Field. Hence, the injection of large volumes of water is unlikely. She suggested that the Livingston Ridge and the Lost Tank Delaware oil fields are unlikely to be waterflooded on a large scale because:

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[10] In a pressure maintenance program, water is injected to supplement declining reservoir energy. Pressure maintenance is a waterflood and often begins while the reservoir is still under primary production to maintain maximum production rates (Willhite 1986, 3, 190).

a) The pay zones are too thin, on the order of forty feet and several wells in the Livingston Ridge area with only ten to twenty feet of casing perforated.

b) The permeability of the Brushy Canyon is less than 7 to 24 millidarcies.

c) For waterflooding to occur, injection wells would have to be spaced closer together, which may be uneconomical.

d) The reservoir has a high irreducible water saturation and a high residual oil saturation.

However, Matthew Silva and Ron Broadhead noted that the Cabin Lake Field, at the northwest corner of the WIPP Site has shown good response to the pilot pressure maintenance project. The reservoirs in the Delaware Mountain Group produce primarily by solution gas drive. Citing the literature, Silva noted that solution gas drive wells are usually good candidates for waterflooding (Willhite 1986). In addition to citing experience and projected performance for the Paduca, Indian Draw, and East Shugart Fields, Broadhead also mentioned there was information, held proprietary by the oil companies operating in the area, indicating that they anticipated 70% to 80% increase in production by waterflooding the Brushy Canyon Formation.

3.2.4 Pay Zone Thickness

Lori Dotson maintained that large scale waterflooding would not occur in the vicinity of the WIPP because the pay zones were too thin. She stated that wells from the Livingston Ridge/Lost Tank portion of the Delaware were perforated for ten or twenty feet and suggested these were indicative of total pay zone potential.

However, a complete assessment of pay zone potential needs to also consider the typical completions for the Quahada Ridge Delaware Pool at the southwest corner

of the WIPP, the typical well completions for the Cabin Lake Delaware Pool at the northwest corner of the WIPP, and the typical multizone well completions for the Livingston Ridge-Lost Tank Delaware.

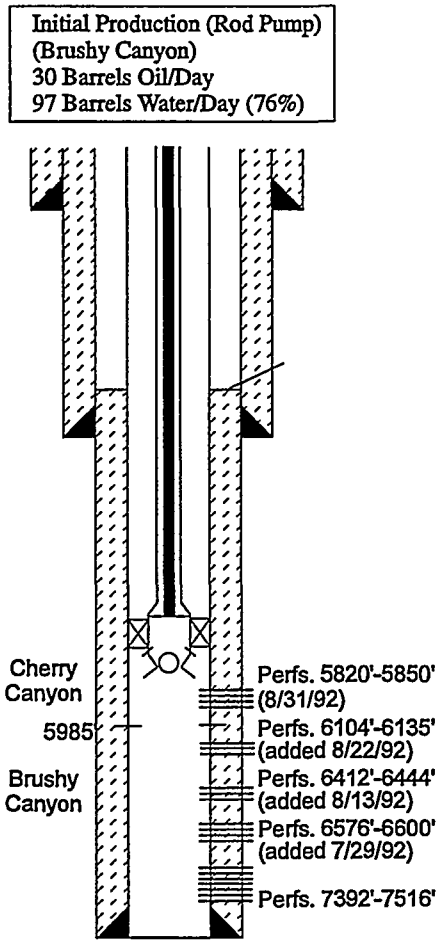


Figure 3-7. James E#12. Typical Cabin Lake Completion. After Dan Stoelzel.

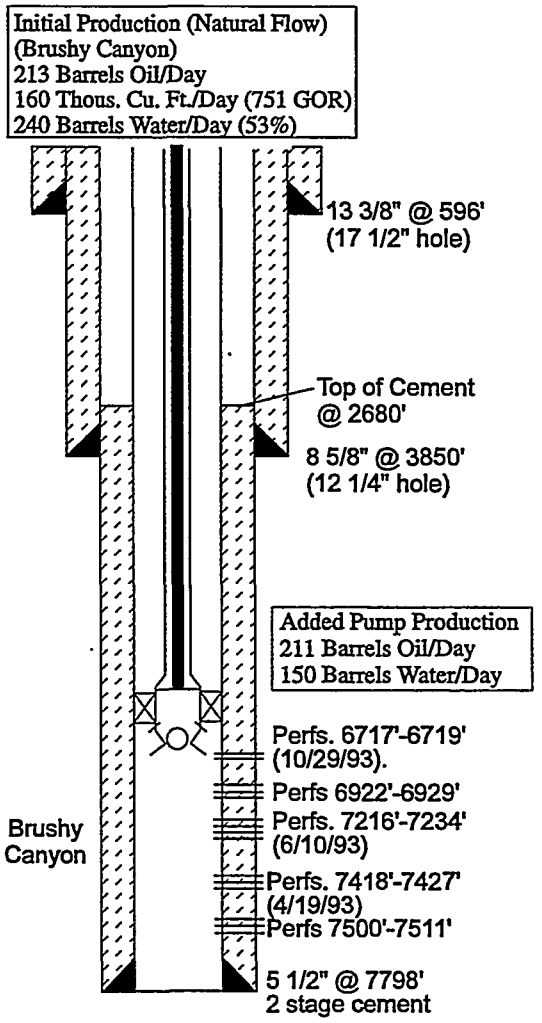


Figure 3-8. James Ranch Unit #19. Typical Quahada Ridge Completion. After Dan Stoelzel.

Stoelzel presented the James E#12 at Cabin Lake as a typical completion with five perforated zones totaling 231 feet (76 m). He presented the James Ranch Unit #19 as a typical Quahada Ridge completion with perforated zones totalling 47 feet (15 m).

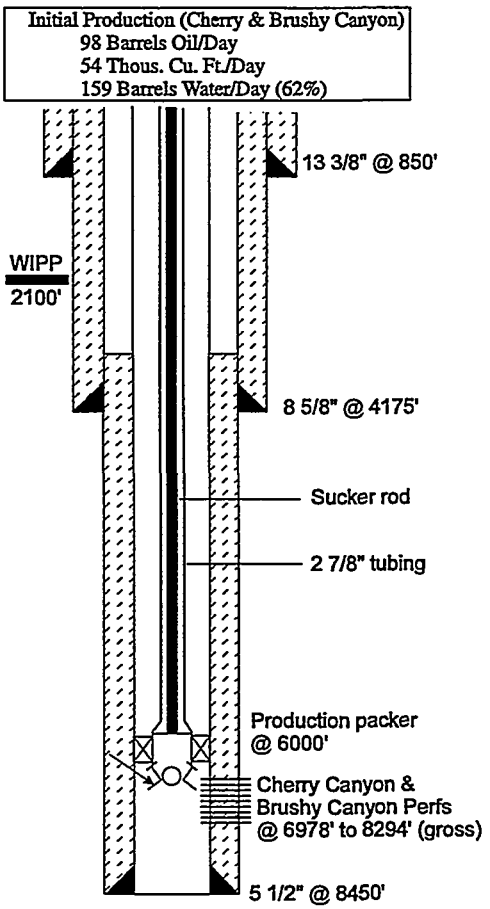


Figure 3-9. Typical Livingston Ridge/Lost Tank Completion. After Dan Stoelzel.

As to the Livingston Ridge/Lost Tank Field, it is true that Pogo Producing's completion records for Federal 23 wells #2, #3, and #5, on the lease immediately adjacent to the WIPP, are completed in the Brushy Canyon main pay zone with perforations ranging from fifteen feet to twenty feet (5 to 7 m). There are, however, other potentially producible zones, such as the B zone and D zone in the Lower Brushy Canyon as shown in Figure 20 of Broadhead et al. (1995). Moreover, the completion record for the Federal 23 Well #1 in that same lease, shows not only 19 feet (6 m) of perforation in the Brushy Canyon main pay, but also shows an additional 91 feet (30 m) of perforations in three other zones that have been temporarily abandoned. Broadhead et al. (1995, XI-16) noted that operators producing only from the main pay zone, at this time, may eventually re-enter their wells and perforate additional zones when the main pay zone ceases to yield economic volumes of oil. The completion records for the twelve additional wells that Pogo wishes to drill on forty acre spacings are not available because the federal government has denied Pogo's application to drill through the potash deposits (Burski 1994).[11]

[11]The EEG understands that this case may be in litigation and the EEG has no implied nor direct opinion in this case.

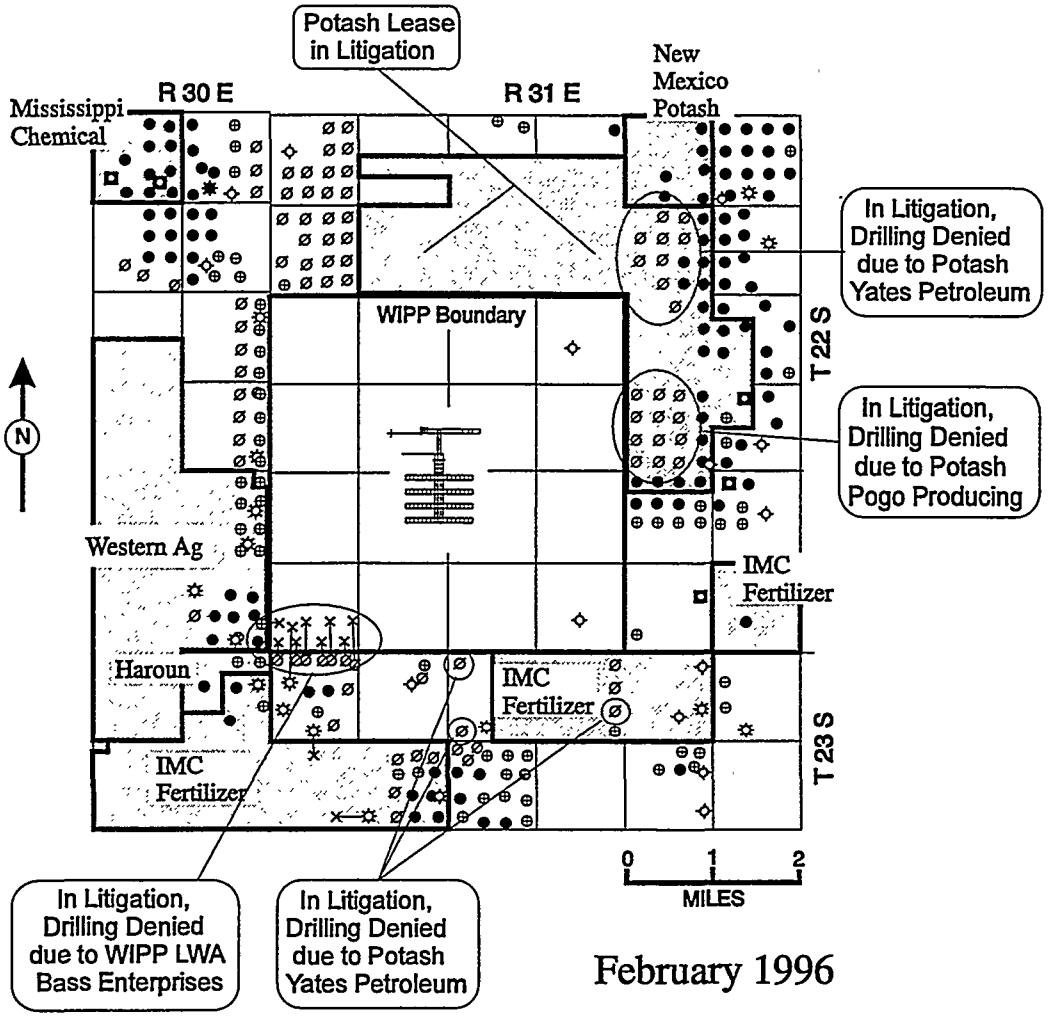


Figure 3-10. Current interest in resources surrounding the WIPP.

In arguing the ten to twenty feet of perforated casing as indicative of no large scale waterflooding, Lori Dotson did not discuss the Yates' wells in the Livingston Ridge. Yates Petroleum has drilled several wells in the west half of the Livingston Ridge but has completed them differently from other operators

(Broadhead et al. 1995, XI-16). All wells are perforated in the main pay and in most cases are also perforated in one to four other sandstones. While some of the completion records provide only the gross interval as shown in Figure 3-9, there is detailed perforation data for the first 3 wells in Section 11, T22S, R31E. Martha AIK Federal Well # 1 was perforated in three zones, 8236'-8308', 7960'-8015', and 7028'-7060', for a total of 159 feet (52 m) of perforations. Well # 2 was perforated in two zones, 6968'-6980' and 7035-7055', for a total of 42 feet (14 m). And Well #3 was also perforated in two zones for a total of 41 feet (13 m). Completion reports for wells #4, #5, and #6 provide only the gross interval of perforations. Wells 7 through 14 are waiting to be drilled. Due to the presence of potash deposits, the federal government has denied Yates' applications for permit to drill wells 7 through 14 (Burski 1994).[12]

3.2.5 Future Decades of Production in Oil Fields Surrounding the WIPP

Three presenters maintained that the oil fields surrounding the WIPP and producing from the Delaware Mountain group will have a maximum production life of less than twenty years. That position contradicts the position of the U.S. Department of Interior's Bureau of Land Management (DOI/BLM) (Woodard 1992, 3).

3.2.5.1 Position of the Department of Interior

The BLM denied Pogo Producing's twelve applications for permit to drill (APDs) in Section 23, T22S, R31E. This lease is immediately adjacent to the eastern boundary of the WIPP site. The APDs were denied because of possible impact on minable potash. Pogo Producing requested a U.S. BLM State Director Review. On March 18, 1992, the State Director of the U.S. BLM listened to a joint oral

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[12]EEG understands that this case may be in litigation and the EEG has no implied nor direct opinion in this case.

presentation by Yates, Pogo, and Texaco. As part of their arguments, Pogo estimated mining operations would not reach the subject area for 20-30 years. During the oral presentation, Pogo's representative and Yates' Engineer maintained that the total projected economic life of the field, including tertiary recovery, would be 15 to 20 years. Therefore, they argued, their oil and gas operation would be completed before potash mining operations reached the area.

However, the BLM noted that the possible deeper gas plays, the current stripper well policy, and the diligence of operations make this estimate of oil field life too short. The BLM maintained that the total economic life could be double the 15 to 20 year estimate (Woodard 1992). In other words, based on its own experience, the BLM anticipates an oil field life of 30 to 40 years.

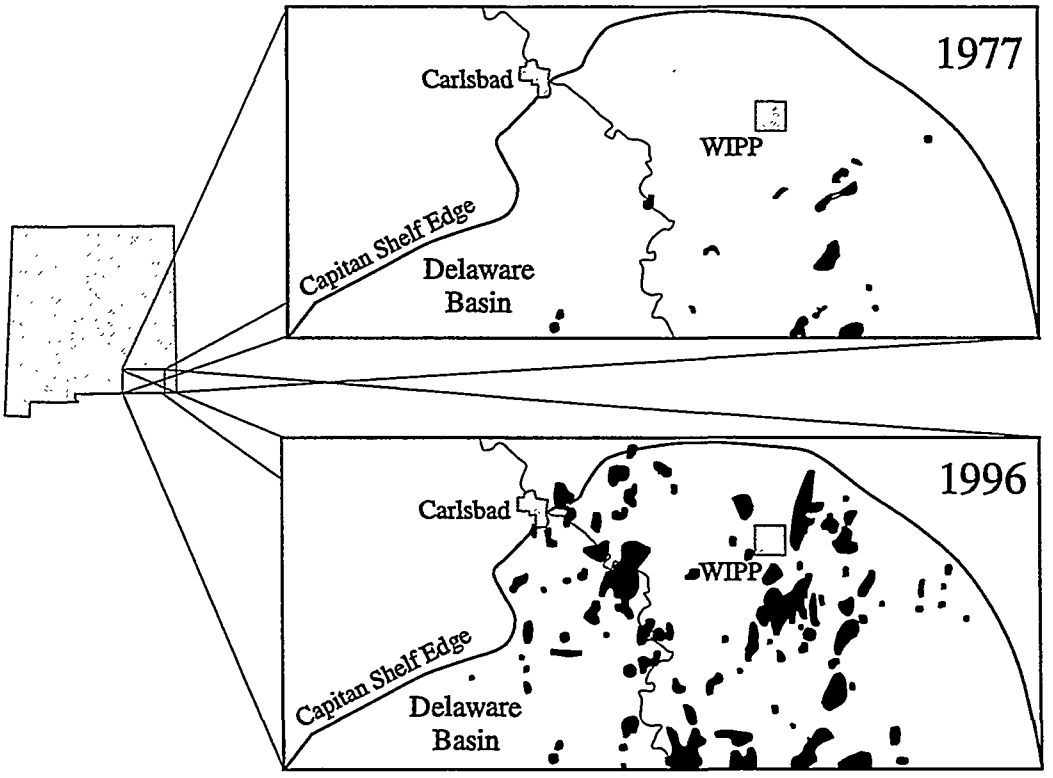


Figure 3-11. Delaware Mountain Group oil fields within the Capitan Shelf Edge of the Delaware Basin. After the Roswell Geological Society (1977) and Broadhead (1996).

Unfortunately, as indicated in Figure 3-11, the oil fields surrounding the WIPP having been only recently drilled, are not yet mature fields and cannot yet provide a direct determination of total field life. However, information in the literature and on public record for mature fields, in other areas of the Delaware Basin, suggest that primary production and waterflooding of the Delaware Mountain Group will generate at least thirty years and as much as fifty years of production after the initial development of a field. This suggests that the longer DOI/BLM estimate of 40 years (Woodard 1992) may be more correct.

Examples of successful waterfloods in the New Mexico portion of the Delaware Basin include Paduca, Indian Draw, and El Mar. The Paduca Field is an example of a successful waterflood that has been in production for over 30 years.

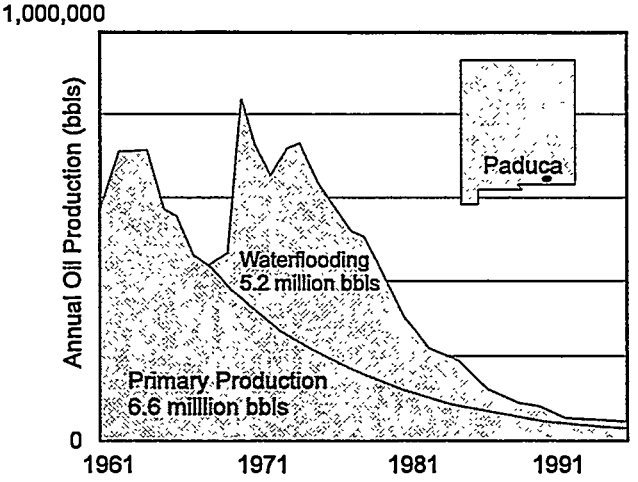


Figure 3-12. Production from Paduca Field. (Broadhead et al. 1995, Figure 38)

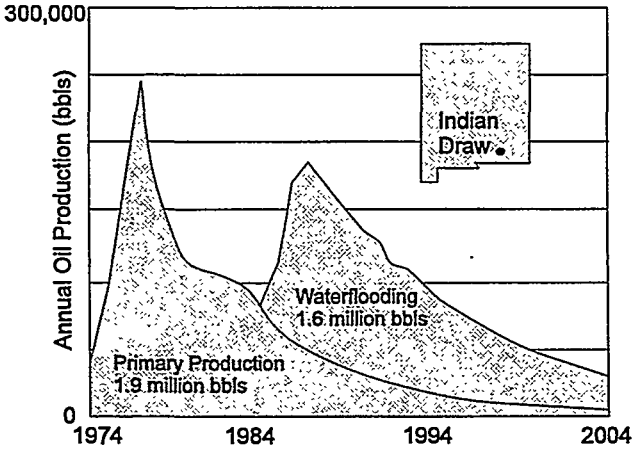


Figure 3-13. Production from Indian Draw. (After Broadhead et al. 1995, Figure 39).

Based on more than twenty years of actual production, including waterflooding initiated in 1980, the projections for the Indian Draw Field also indicate an anticipated oil field well life beyond 30 years.

One company operating in the Livingston Ridge area adjacent to the WIPP has submitted an affidavit which tends to support the position of a maximum of twenty years of operation (Boneau 1992, 2). Yates Petroleum maintains that oil and gas can be produced before any potash mining begins in this area (Boneau 1992, 2; Carroll and Bogle 1995, 33). As Broadhead (1995, XI-16) noted, Yates multiple zone completion practices are different from other operators in the area. Boneau states that Yates can complete primary and secondary development within 12 to 15 years. In the event of tertiary recovery, such as CO_2 flooding, the time would be extended by about five years for a maximum oil field life of twenty years. However, attorneys for Yates maintain that if there is waterflooding, "... the time to produce both primary and secondary oil should be in the range of 30 to 35 years" (Carroll and Bogle 1995, 33).

Comments by the University of Oklahoma Petroleum Engineering Professor Ron Evans at the EEG workshop tend to support oil field lifetimes closer to forty years:

> I will make this statement based on my experience in areas of Oklahoma. I do not believe that you are going to see oil production in the Delaware Basin cease totally in the next 20 years. I don't think that is going to happen. The tendency is like the food chain. You have the little people and you have the big people. Eventually it's the little people that are going to have that area and they'll tend to operate longer than say an Arco or Mobil would. I do not believe, for oil in the Delaware Basin, that production will cease within 20 years. I think it will be there 40 years from now because it will be in the hands of small operators.

3.2.5.2 Avalon Waterflood

Exxon (Bruce 1995c) filed for approval of an enhanced oil recovery project for the proposed Avalon Delaware Unit on May 9, 1995. The Avalon Field is about eight miles west of the potash area, hence the application is not encumbered by

the presence of potash. Specifically, Exxon proposes to inject water into the Cherry Canyon and Brushy Canyon members of the Delaware Mountain Group to promote oil recovery. Cantrell and Kane (1993) describe the geology and history of primary production in detail and note average permeabilities of 1.5 millidarcies (md) for the upper Cherry Canyon Formation and 1.1 md for the lower Cherry Canyon and upper Brushy Canyon Formations.

As noted in the unitization proposal (Bruce 1995b), Exxon projected that a waterflood would extend the producing life of the unitized formation beyond the year 2030. As Exhibit #3, Exxon plotted projected waterflood operations beyond the year 2040 for a field that began oil production in 1983. In terms of total field life, Exxon projects this field will be producing for at least fifty years.

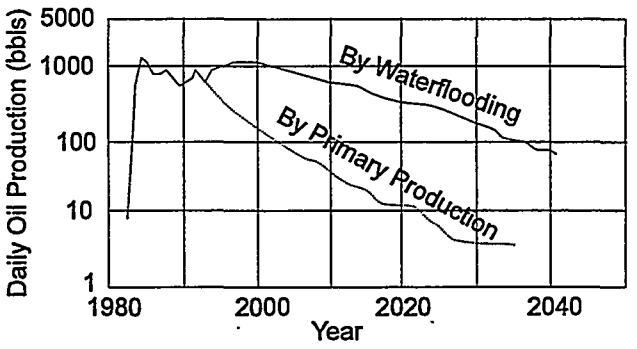


Figure 3-14. Waterflood vs. continued Primary Recovery at the Avalon Field (After Bruce 1995c).

3.2.5.3 Twofreds Waterflood and CO_2 Flood

The Twofreds Field, discovered in 1957 and developed by Mobil, is another example of the sequence of events, problems, and production longevity that might be anticipated for oil fields in the vicinity of the WIPP. The Twofreds is about 3/4 mile wide and is about five miles long with a net thickness averaging about 16 feet (5 m).

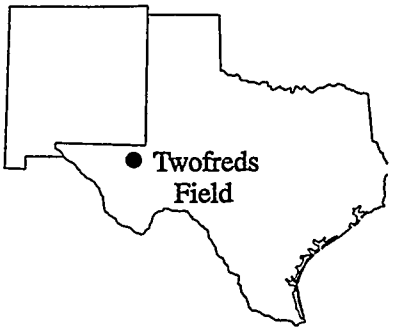


Figure 3-15. Location of Twofreds Field.

The Twofreds Field, like other Delaware fields, has always produced large volumes of water. After six years of primary production, a pilot water injection project with four injection wells was initiated in May 1963. The Twofreds was the first unitized waterflood in the Delaware Basin (Kirkpatrick et al. 1985). Success of the pilot project led to a full scale waterflood with 21 additional injection wells brought on line in January 1966. The waterflood project showed that oil from a Delaware reservoir with a high water cut could be recovered profitably (Jones 1968).

Early estimates anticipated that the Twofreds field would be depleted by 1975. However, carbon dioxide flooding extended the productive life of this field. HNG Fossil Fuel Company acquired the field from Mobil in 1973 for the purpose of initiating a carbon dioxide flood.

At the time of acquisition by HNG, most of the wells were in poor mechanical condition. Only 12 of the 89 wells were producing. Total field production ranged between 150 and 160 bbls oil per day. When the best producing well quit, total field production dropped to 100 bbls oil per day. There was a hole in the casing of the failed well. Many of the other production wells had been abandoned with rods, tubing, and other junk left in the well bores. And although the injection wells had been in waterflood service less than ten years, many had to be reworked to correct channelling problems. In some cases, the water had fingered through some zones, causing channels and leaks around the casing. These had to be repaired to prevent carbon dioxide from leaking out of the productive zone (Wash 1982)

By design, the Twofreds carbon dioxide injection wells were operated very close to the fracture pressure. Surface injection pressures were maintained at 1400 psi which resulted in a downhole bottom pressure of 3,000 psi, only about 100 psi below the fracture pressure. In describing the automatic pressure controls, the field superintendent, W.C. Mason noted:

We walk a fine line between injection pressures and fracture pressures. If we were to exceed the fracture pressures, the gas would channel up the pipe and get out of zone. Therefore, we'd lose the drive off that well and all the oil that would have been pushed by the CO_2 (Wash 1982).

From 1957 to 1973, primary recovery produced 6.6 million bbls oil. From 1963 to 1973, secondary recovery produced 2 million barrels oil. By 1982, carbon dioxide flooding had produced an additional 2 million barrels of oil (Wash 1982). Carbon dioxide flooding increased oil recovery from 160 bbls oil per day to 1,000 bbls oil per day.

The purpose of the Twofreds carbon dioxide flood was to demonstrate economic feasibility. The field continued to produce based on its economic merit (Kirkpatrick et al. 1985) and demonstrated that carbon dioxide can economically recover tertiary oil from a depleted, waterflooded Delaware sand reservoir (Flanders and DePauw 1993). As of 1993, oil production from the Twofreds was averaging about 500 bbls oil per day (Flanders and DePauw 1993). The Twofreds Field clearly shows that even in a field where the reservoir energy is quickly depleted, fluid injection can improve oil production and add decades to the productive life of a Delaware Basin oil field.

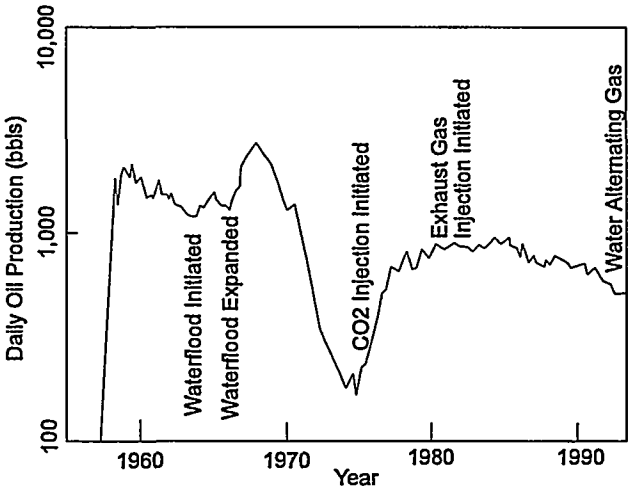


Figure 3-16. Production history of Twofreds (After Flanders and DePauw 1993).

3.2.5.4 El Mar Waterflood and CO_2 Flood

Independent operators continue to explore ways to extend the life of oil field production in the Delaware Basin. The El Mar has been producing from the Bell

Canyon Formation of the Delaware Mountain Group by primary recovery since 1959 (Porter 1966) and by waterflooding since 1968 (Broadhead et al. 1995).

In 1988, Union Royalty purchased the El Mar Unit from Texaco and others. In 1993, the unit was a mature waterflood producing about 140 bbls oil per day. Union Royalty planned to increase production to 2,000 bbls per day using carbon dioxide flooding. In exchange for an interest in the produced oil, Amoco would supply carbon dioxide through a pipeline to be built by Enron from the Dollarhide Field (Moritis 1993). If the success of the Twofreds project is any indication, the El Mar, which has been producing for 37 years can anticipate two or three additional decades of production.

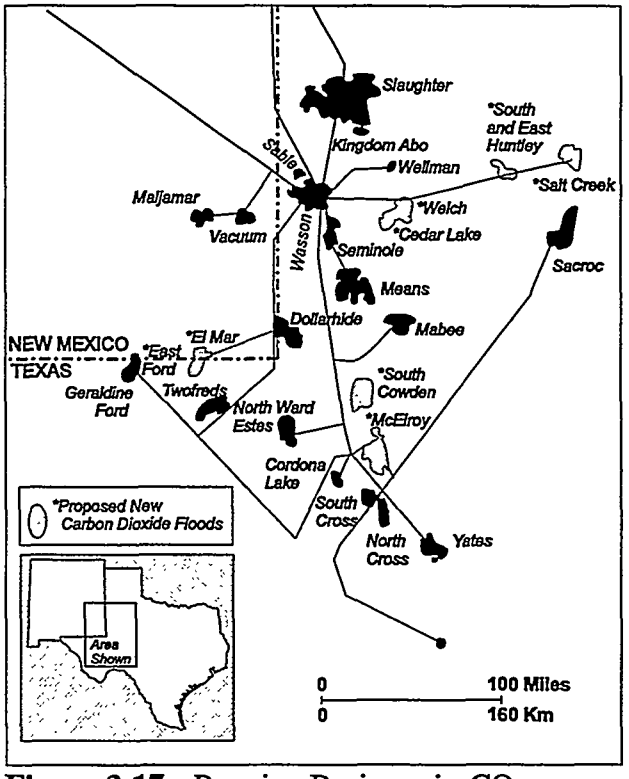


Figure 3-17. Permian Basin main CO_2 pipelines and CO_2 floods (Moritis, 1993).

3.2.6 Waterflood Volumes Around the WIPP

Lori Dotson maintained that waterflooding would not be a problem for the WIPP because such activity, if it occurred, would not be on the same scale as the Rhodes-Yates Field or the Vacuum Field waterfloods. There was disagreement about the amount of water needed to waterflood the oil fields surrounding the WIPP. Matthew Silva suggested that at WIPP, for ten million barrels of oil recoverable by waterflooding, 100 million barrels or more of injected water would

be needed. Stoelzel questioned whether that amount of water would be used for such small pools of oil.

Waterflooding in the vicinity of the WIPP is just beginning and, thus far, experience is limited to pilot pressure maintenance programs. The proposed Avalon Unit provides insight into the anticipated amount of water that is needed to recover oil by waterflooding the Cherry Canyon and Brushy Canyon members of the Delaware Mountain Group. This field lies approximately eight miles west of the potash enclave and is not constrained by the presence of potash. At Avalon, Exxon, has calculated that an additional 8.2 million barrels of oil (Bruce 1995c) will be recovered by injecting 141 million barrels of water through nineteen injection wells. Hence, the anticipated ratio of water injected to oil recovered, for the forty-year life of the project, is 17.2.[13]

For the one mile band surrounding the WIPP Site, Broadhead estimated 13.8 million barrels of the proven and probable crude oil reserves that could be recovered by waterflooding. Assuming the Avalon injection ratio of 17.2, for the life of such a project, one can estimate the volume of injected water will be 237 million barrels of water.

Texaco's Rhodes-Yates Lease was two miles away from Hartman's Bates Lease. Assuming that 29 million barrels of oil can be recovered by waterflooding (0.66 million barrels oil per section) and an injection ratio of 17.2 barrels water per barrel oil, for a two-mile band about WIPP, 500 million barrels of water could be injected over the life of these waterfloods. Of course, this simple estimate of future waterflooding must be viewed with caution. It is based on the estimated performance of an analog and is limited to the extrapolation of only proven and

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[13]The capital cost for the waterflood facilities at Avalon is estimated at $14.4 million and the estimated value of incremental production recovered from this project is estimated at $123 million based on a crude oil price of $15/ barrel (Bruce 1995a, 3).

probable reserves. It does not include possible reserves or undiscovered reserves of oil and gas underneath potash deposits.

Nonetheless, how does an anticipated 500 million barrels of water injected in the vicinity of WIPP compare with the Rhodes-Yates Field? At Rhodes-Yates, from 1964 through 1991, Texaco had injected approximately 41 million barrels of water through eighteen injectors (Hartman 1993, 5). This simple comparison strongly suggests that WIPP will eventually be surrounded by waterflood operations at least on the scale of the Rhodes-Yates Field and demonstrates that the two are comparable.

Actually, the pressure maintenance programs underway in the immediate vicinity of WIPP are already injecting far greater volumes of water than was injected in the pilot pressure maintenance program at Texaco's Rhodes-Yates Unit. Water from the two pilot injection wells at Rhodes-Yates totaled two million barrels from 1964 to 1974 or approximately 100,000 barrels water per well per year for a ten year period. Pogo Producing plans to inject 365,000 bbls of water per year into one well one mile east of the WIPP as part of its pilot pressure maintenance program in the Livingston Ridge Field.

At the Cabin Lake Unit, at the northwest corner of the WIPP Site, Phillips Petroleum has already begun operating two pressure maintenance wells. Water injection for pressure maintenance was initiated at the James A Well No. 12 (Sec 2, T22S, R30E) on February 18, 1992, and the James A Well No. 3 (Sec 2, T22S, R30E) on November 8, 1993 (Telford 1995). The volume of water injected through the James A Well No. 12 was 945,000 bbls for 1992, 1,121,000 bbls for 1993, and 738,000 bbls for 1994. The volume of water injected through the second pressure maintenance well in this area, the James A well No. 3 was 618,000 bbls for 1994. Based on the 1994 figures, these two wells are averaging approximately 1.4 million bbls water injected per year compared with 200,000 bbls water injected per year through the two pilot pressure maintenance wells at

Rhodes Yates. Furthermore, within ***three years*** of the initial operation, these two wells at the northwest corner of the WIPP Site had already injected four million barrels. This is more than twice the amount of water that was injected into the two pilot injection wells at Rhode-Yates in the ***ten year*** period following the initial operation of those wells. These observations strongly suggest that for the WIPP, the large scale waterflooding scenario cannot be ruled out on the basis of insufficient water injection.

In evaluating potential scenarios for the WIPP, the Hartman vs. Texaco case also demonstrates the need to consider the experience of other waterfloods despite any difference in size, in conditions, or in persons involved. Texaco argued to "exclude testimony relative to events or matters occurring in the waterfloods other than the Rhodes Yates waterflood, and to prohibit reference to other waterfloods by counsel for plaintiffs" (Lanphere and Sullivan 1994c; 1994d). Specifically, Texaco's attorneys maintained:

> On the other hand waterflood areas studied with respect to the 1977 hearings were larger waterflood projects than Rhodes Yates....
>
> The events in this case are vastly dissimilar in many respects to the events in the earlier waterfloods. There are fewer wells in the present field than were drilled in the earlier fields (Lanphere and Sullivan 1994d, 3,5)

Hartman's attorneys countered with the following argument:

> Texaco seeks to exclude by its Motion a wealth of data which correlates waterflows in Lea County to waterflood operations. The correlation is based upon public record documents which were generated by, among others, Texaco. The documents indicate that in the mid-1970s the New Mexico Oil Conservation Division determined that waterflood operations were causing waterflows, caused various operators, including Texaco, to establish committees to look into the issue, investigated specific injection

> wells and other aspects of waterflood operations in order to deal with the problem and never investigated naturally occurring sources of water as a potential explanation for waterflows which began to be reported after the start up of waterflood operations. The evidence shows that such waterflows were not randomly distributed, but are strongly correlated to waterflood operations (Gallegos and Condon 1994, 2).

In evaluating potential scenarios, the WIPP project needs to fully consider the experience of other waterfloods, particularly in light of the experience of oil fields overlain by the Salado. Such experience should not be rejected on the basis of difference in size (larger or smaller), differences in conditions, or differences in persons involved. There appears to be a technical basis as well as legal arguments for such consideration.

3.2.7 Availability of Water

Will there continue to be enough water for secondary recovery? Ron Evans commented on the increasing availability of water for oil field operations.

> If you look at water production in the United States, it has been going up significantly faster than overall oil production. We are producing more and more water in the United States than we ever have, in the oil producing regions of the United States.

More specifically, the volumes of water already being injected in the Delaware Basin, either for salt water disposal or pressure maintenance, do not hint at any water shortages for the purposes of oil field waterflooding. For example, the David Ross "AIT" Federal #1 salt water disposal well approximately one mile east of the WIPP Site typically injects between 80,000 and 100,000 barrels of brine per month. Other wells in the vicinity each typically inject volumes ranging between 10,000 and 100,000 barrels per month (Curry 1995; Hunt 1995; Garcia 1995;

Horsman 1995). Presumably, that water could be made available for waterflooding as reservoir pressures decline.

3.2.8 Formation and Well Bore Damage by Nitroglycerin Stimulation

Dan Stoelzel and Lori Dotson suggested that the practice of nitroglycerin blasting caused extensive formation and well bore damage in Rhodes-Yates Field and the Vacuum Field. They further maintained that because such practices are no longer used, there will be no such completion problems in the vicinity of the WIPP. The DOE has also adopted the position that the problems with Texaco's well completions in the Jal area resulted, in part, from the use of nitroglycerin blasting to stimulate the formation (McFadden 1996). However, the comments of Ron Evans tend to contradict the notion of extensive formation damage by nitro-fracing:

> The reason nitro-frac went out of business is because hydraulic fracturing is a superior stimulation technique. Hydraulic fracturing will give you much greater productivity increases than any nitro-frac ever did and that's well documented. Nitro-fracturing, as it was carried out in the late 40s and early 50s, did not destroy the cement shield. You can do the calculations and show, they place that little charge in the center of the formation and the maximum you could get would be of the order of about seven to ten feet zone of change in the radial direction and on the order of 15 feet in the vertical direction. That never even got you out of the Yates formation.

Hartman maintained that the excessive injection pressures in Texaco's Rhodes-Yates waterflood caused the salt water blowout on the Bates Lease. In commenting on the history of waterflood problems in New Mexico, Ramey (1995, XI-2) also states that water probably escaped from the injection zone and into the salt formations as a result of old improperly cemented and plugged wells and excessive injection pressures in oil field waterflood operations. These observations by Evans, Hartman, and Ramey, strongly suggest that stimulation by

nitroglycerin fracturing was not the source of the problem. Rather, it was argued that excessive waterflood injection pressures were the problem (Hartman 1993; Van Kirk 1994).

3.2.9 New Injection Well in Excess of WIPP Lithostatic Pressure

Pogo Producing recently requested and received approval from the New Mexico Oil Conservation Division to operate a pressure maintenance well one mile east of the WIPP site at a maximum surface injection pressure of 1410 psi (9.7 MPa) (LeMay 1995b). Public notice was given and a hearing was held on November 16, 1995. The results of the hearing included the following findings:

> (5) IMC Global Operations, Inc. (IMC), a potash operator in this area, appeared at the hearing and expressed concerns about permitting injection wells in close proximity to potash mining operations. Specifically, IMC is concerned that injected fluid will escape or otherwise migrate from the proposed injection interval into potash bearing formations.
>
> (6) Testimony presented in this case indicates that potash mining operations occur at depths of approximately 1,300 feet to 2,000 feet.
>
> (7) Evidence and testimony present by the applicant indicate that the proposed pilot pressure maintenance project is located:
>
> > a) within the Known Potash Leasing Area as describe within Division Order No. R-111-P;
> >
> > b) directly adjacent to a potash lease which encompasses portions of Section 3 through 5, 8 through 11, 13 through 14, 23 through 24, and 26, Township 22 South, Range 31 East, NMPM. The ownership of this potash lease is undetermined at this time due to ongoing litigation between IMC Global Operations, Inc. and Yates Petroleum Corporation;
> >
> > c) approximately eight miles from IMC's existing potash mine workings; and,

d) one mile from the outer boundary of the Waste Isolation Pilot Project (WIPP)

(8) The applicant notified the Department of Energy (DOE) of its application in this case, however, no representative of that agency appeared at the hearing. (LeMay, 1995b).

The findings also state that injection at an initial surface injection pressure of 1,410 psi should not result in the fracture of the proposed injection interval or confining strata. The well is designed such that the intended horizon for injection is approximately 7,000 feet below the surface.

But in the event of a leak, channeling behind casing, or movement through a vertical fracture, can brine be injected into the Salado Formation? In such an event, under the sustained pressure of a waterflood, what is the fracture pressure of the Salado Formation at the WIPP horizon and what is the hydrostatic pressure of the injected fluid at the WIPP horizon?

The lithostatic pressure at the WIPP horizon is 14.9 MPa (2160 psi). Assuming a brine with a specific gravity of 1.1 and an approved surface injection pressure of 9.7 MPa (1,410 psi), the injected brine can exert a hydrostatic pressure of approximately 16.8 MPa (2440 psi) at the WIPP horizon.

With respect to anhydrite or interbed fracturing, the WIPP conceptual model assumes that repository fracturing or dilation of existing fractures will be less than the lithostatic pressure (Howarth et al. 1995, Section 2.1.2.2). That assumption largely reflects experimental evidence in the excavated areas where the stress fields have been substantially changed. The anhydrite at the injection well bore may or may not be fractured, either naturally or by the drilling activity. Interbeds contain natural fractures which may be partially healed (U.S. DOE 1995, 6-73).

Experimental results indicate the fracture pressure for intact rock to be higher than lithostatic (Beauheim et al. 1993). However, the experiments of Beauheim et al. (1993) were designed to last only a few minutes, hence, they subjected the rock to a very rapid increase in fluid pressure. An injection well operates on the order

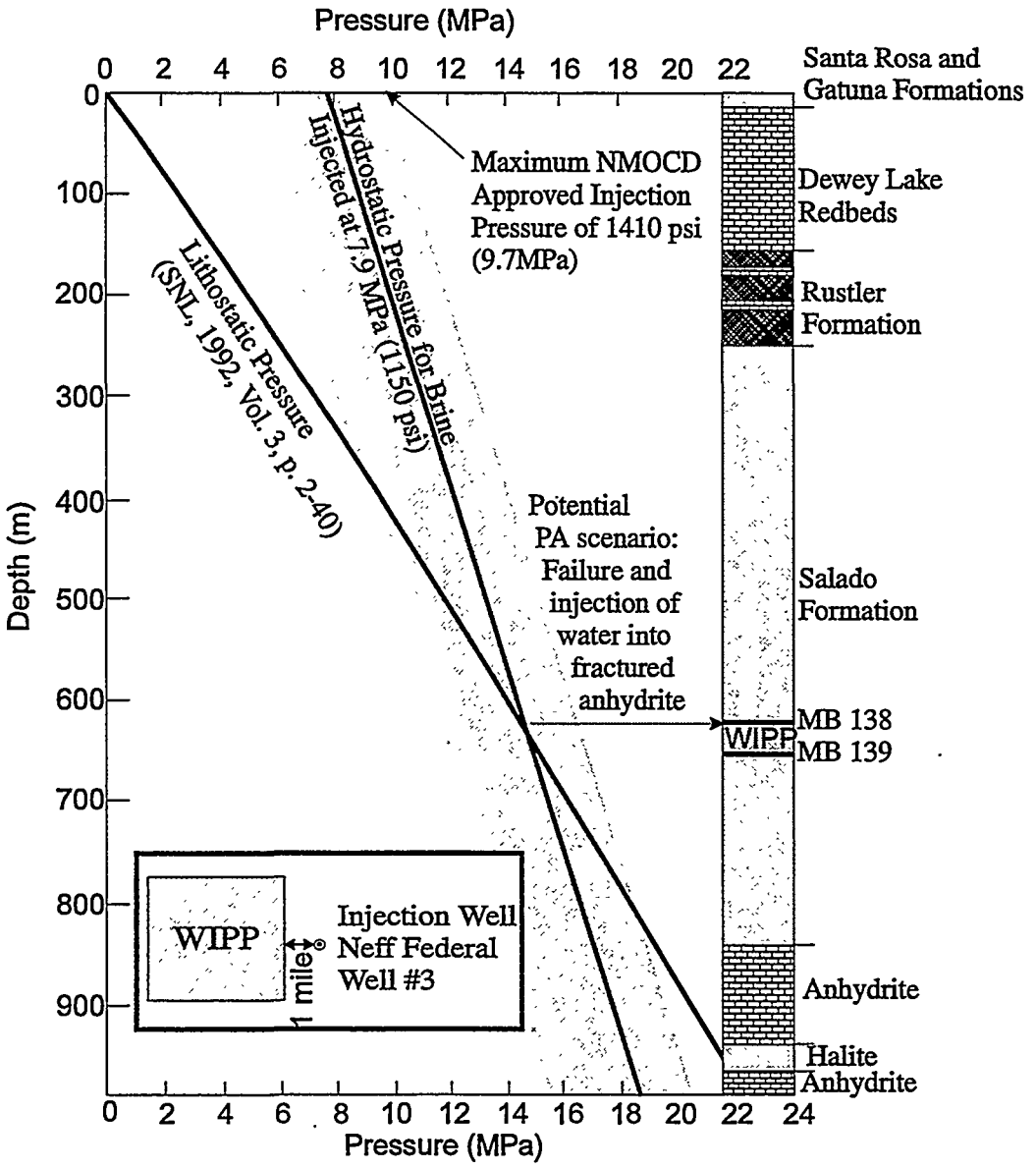


Figure 3-18. Approved Injection Pressure for Neff Federal Well #3 and Potential PA Scenario.

of years or decades. For fracture initiation and vertical fracture propagation, fracture pressures are lower for formations penetrated by an invading fluid (Haimson and Fairhurst 1967, Fairhurst 1968). Atkinson (1987, Chap. 4 and 5) also cautions about subcritical crack growth in the presence of a chemically active environment.

Rather than speculate on the potential for creating a new fracture or propagating an existing fracture in an anhydrite or other marker bed under pressure for a long period of time, this report notes that a pressure maintenance well, approximately one mile from the WIPP, has been approved to operate at an injection pressure 1.9 MPa (280 psi) above the lithostatic pressure at the WIPP horizon. Such a well typically injects brine over a period of several years. The plot of lithostatic pressure and hydrostatic pressure strongly suggests that, in the event of communication, fluid can be potentially injected into the anhydrite beds of the Salado Formation very near the WIPP horizon.

3.3 Regulations and the Salt Isolation Casing String

As noted by Dan Stoelzel, new state regulations require a salt isolation casing string for all wells drilled in the WIPP area. There are no specific oil and gas regulations that apply specifically to WIPP (Ramey 1995). Rather, the WIPP Site is located within the Potash Area near the eastern boundary. As a result of NMOCD Order R-111-P, signed April 21, 1988, all wells completed within the potash area must have a salt isolation string intended to protect the salt section from the intrusion of water and oil and gas (Ramey 1995, IX-1).

At the workshop, Armando Lopez (BLM) noted that a salt isolation string is not required for wells approximately one mile east of the WIPP Site. Exhibit A of R-111-P shows that Sections 26 and 35 (T22S, R31E) lie immediately adjacent to the WIPP site but are not part of the Known Potash Leasing Area. Hence, it appears the salt isolation string may not be required for all oil and gas wells completed in the vicinity of the WIPP.

In 1980, the Department of Energy intended to prohibit waterflooding within former control zone IV (U.S. DOE 1980, 8-4). The DOE surrender of that control was not based on any protective state or federal regulations, but on a report (Brausch et al. 1982) that incorrectly concluded that there would be no waterflooding because there was minimal recoverable oil.

As noted above, the state regulations for completing wells in the potash enclave are not specific to WIPP. In fact, R-111-P (LeMay et al. 1988) addresses only the incompatibilities between the activities of oil and gas production and potash production and does not mention WIPP. With respect to federal regulations, the Secretary of Interior makes it clear that one intent of the order is "to prevent the infiltration of oil, gas, or water into formations containing potash deposits or into mines or workings being utilized in the extraction of such deposits" (U.S. DOI 1986, III.A.4) However, this order is not intended to protect WIPP. Further, despite the salt isolation string requirement, federal and state agencies still restrict drilling for oil and gas through potash reserves or near potash mining operations.

Rather than rely on the intent of new regulations coincidental to the WIPP area, the DOE should fully consider the actual experience and implementation of existing regulations with respect to fluid injection. Such regulations have been in place for decades and provide a measure of the reliability. For example, the enabling orders for the Rhodes Yates waterflood (Campbell et al. 1964; Cargo et al. 1969; Ramey 1977) required operating in accordance with Rules 701, 702, and 703 (Hartman 1993, 4). Rule 702 requires cementing and casing of injection wells to prevent the movement of fluids out of zone. Rule 703 requires operation and maintenance practices to assure no significant fluid movement through vertical channels adjacent to the well bore. Further, the entire operation, including producing wells, must be operated and maintained to confine the injected fluids to approved intervals. The documented problems with the Rhodes Yates waterflood (Hartman 1993; Hererra 1995) and with waterfloods and salt water injection throughout the southeast New Mexico (Ramey; 1976; U.S. GAO 1989; Bailey 1990; Krietler 1994) clearly indicate the limitations of taking credit for state or federal regulations, new or old, for protecting WIPP.

3.4 Safety Analysis Report and Water Injection

Bill Bartlett (EEG) voiced concern at the workshop that waterflooding may need

to be considered in the Safety Analysis Report (SAR) for operations. George Dials noted that waterflooding should be considered in the Final Safety Analysis Report only if data exists which shows a high probability event that could adversely affect the WIPP during the 35 year operating life. George Dials added "there is waterflooding going on in the vicinity of the WIPP as has been discussed today. And we see no great increase in brine inflows and no great increase in moisture or anything else in the facility."

It appears that even small increases in the water inflow into the facility have an impact on the continuous air monitors. WIPP operations rely on continuous air monitors to detect a release of radionuclides. This detection is needed to divert the flow of any contaminated air through the HEPA filters. Water flowing into the exhaust shaft at a depth of approximately 50 to 100 feet (16 to 33 m) was identified as a potential problem for continuous air monitoring. In a report on continuous air monitoring, Bartlett and Walker (1996) commented that air flow through the sampling filter would be reduced as salt aerosol and moisture combine and collect on the filter. Low air flow through the filters at an underground air sampler was observed in 1994 and 1995. Moisture was the likely cause, strongly suggesting that water leakage problems can influence CAM performance (Bartlett and Walker 1996, 39).

Samples collected near the exhaust shaft collar by the DOE have been analyzed (Dials 1996).[14] The samples were analyzed for metals and inorganic compounds, but there was no analyses for hydrocarbons. Although there has been an effort to determine the source of the water (Westinghouse 1995, 1996a, 1996b, 1996c), it appears that the source of this water remains unknown. Hence, questions remain. What is the source of the water? At what rate of water inflow does the intruding

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[14] The inflow of water into the exhaust shaft was not discussed at the EEG workshop.

water create a problem for the air sampling system? And what happens when the water-flooding and brine injection activities become common place around the WIPP?

3.5 1995 DCCA - Features, Events, and Processes

When asked by Don Hancock (SRIC) how Sandia was going to determine the probability of waterflooding, Peter Swift (SNL) clarified that a feature, event, or process can be eliminated on the basis of one screening criterion. The three criteria of probability, consequence, and regulatory, are not all applied to each case. For example, if waterflooding is eliminated on the basis of "regulatory" criteria or "consequence" criteria, then there is no need to assign a probability. There is no need to calculate a consequence for an FEP that has been eliminated on the basis of another criteria. He also commented that he was not prepared to say how the project was going to screen waterflood FEPs. But he felt that an injection well failure at markerbed 139 with fluid migrating towards the WIPP site would be a low probability event that would be difficult to quantify.

On July 31, 1995, six weeks after the EEG workshop on waterflooding and salt water disposal, the DOE submitted a Draft Compliance Certification Application to demonstrate DOE met the requirements of the EPA Standards for the disposal of transuranic waste. As in 1991 and 1992, fluid injection was ***not*** included in the performance assessment calculations. All fluid injection was screened out on the basis of "regulatory guidance" (U.S. DOE 1995, 6-38). Furthermore, some human initiated events such as recent and ongoing fluid injection outside the controlled area were screened out on the basis of low consequence. No supporting documentation was supplied. Supporting documentation would be supplied with the final compliance application (U.S. DOE 1995, SCR-72).

The 1995 DCCA maintains that the screening procedure "is similar to that proposed by Cranwell et al. (1990, 5-10) and used in the 1991 and 1992 WIPP performance assessments" (U.S. DOE 1995, 6-2). However, Cranwell et al.

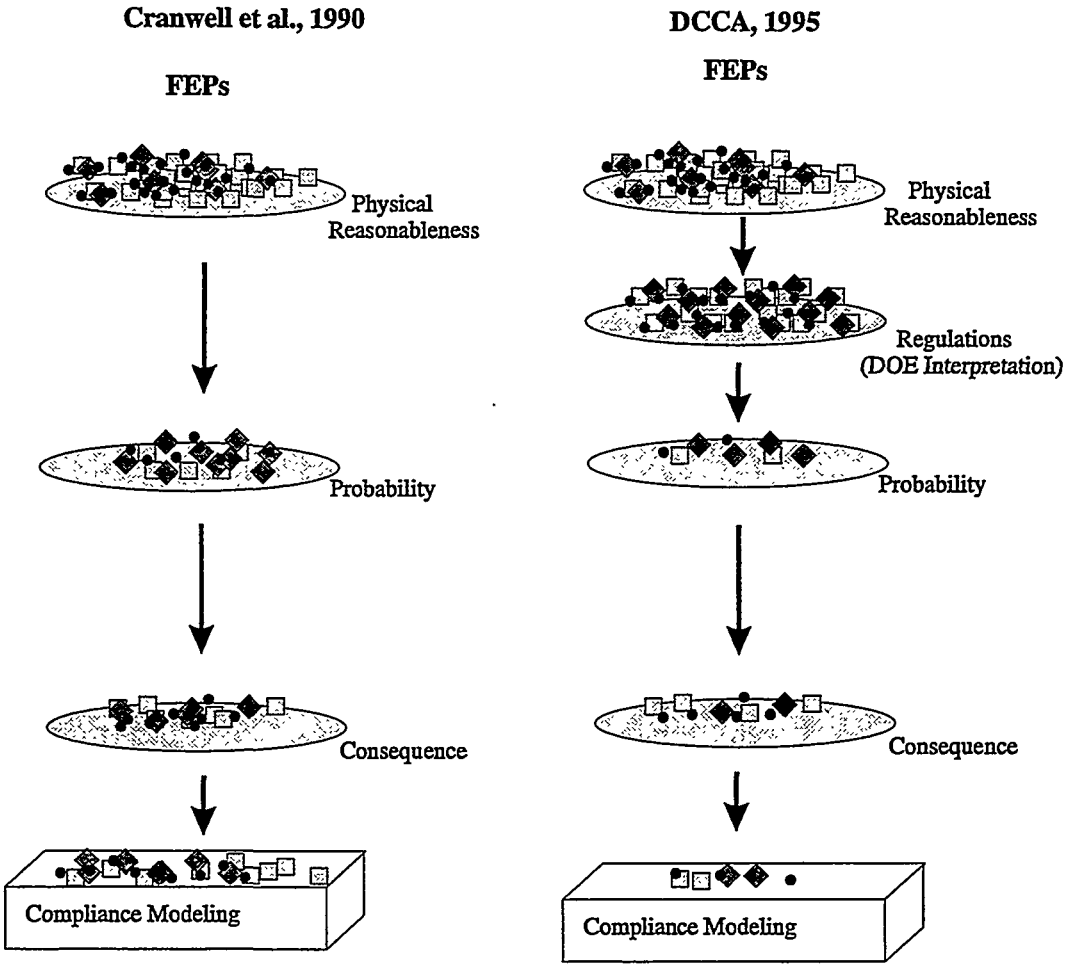


Figure 3-19. "Regulatory" sieve unique to WIPP.

(1990) did not discuss a "regulation" sieve to eliminate otherwise viable scenarios from consideration. This sieve is unique to WIPP (SNL 1992, Vol. 2, 4-3). Further, an inspection of the "regulation" sieve reveals it to be an interpretation of the non-binding guidance by the WIPP Performance Assessment Department which allows the WIPP Performance Assessment Department the latitude to eliminate any inadvertent human activity that could result in a consequence greater than those of exploratory drilling (SNL 1992, 4-4).

3.6 EPA Final Criteria (40 CFR 194) and Compliance Application Guidance

As required by the 1992 WIPP Land Withdrawal Act, the EPA published Criteria,

(U.S. EPA 1996a) for determining if the Waste Isolation Pilot Plant will comply with the EPA's environmental radiation protection standards for the disposal of radioactive waste. The EPA also published the Compliance Application Guidance (U.S. EPA 1996b) as a companion to the final rule.

The EPA Final Criteria for the disposal of transuranic waste requires the DOE performance assessment to address the issue of waterflooding and salt water disposal with the following language:

> Performance assessments shall include an analysis of the effects on the disposal system of any activities that occur in the vicinity of the disposal system prior to disposal and are expected to occur in the vicinity of the disposal system soon after disposal. Such activities shall include, ***but shall not be limited to*** [15], existing boreholes and the development of any existing leases that can be reasonably expected to be developed in the near future, including boreholes and leases that may be used for fluid injection activities (U.S. EPA 1996a, 40 CFR 194.32 (c)).

As stated in the EPA Compliance Application Guidance (U.S. EPA 1996b):

> EPA recommends that the terms "near future" and "soon after disposal" for oil and gas drilling be considered to consist of the expected lives of the oil and gas fields in existing leases that can be reasonably expected to be developed in the vicinity of the WIPP.
>
> For mining, the terms "near future" and "soon after disposal" should be applied to the estimated lives of existing mines and plans for new mines in the vicinity of WIPP. EPA recommends that DOE use minable reserves in estimating mine lives and the extent of potential mining. When establishing the rate of growth for mines, DOE should consider both the

[15]Emphasis added.

historical growth for mines and the potential for new mines that may be developed in the vicinity of WIPP.

3.6.1 Near Future

For the WIPP project, the DOE has already elicited expert opinion on the definition of *near future* with respect to the recovery of natural resources in the vicinity of a 10,000 year repository.

> For the Boston Team, the near future is 0-300 years after the lapse of institutional controls (100 years after closure). The Southwest Team used a 100-500 year period after closure for the near future while the Washington A Team use the first 200 years after the lapse of active controls. The Washington B Team also adopted a 200-year definition for the near future (Hora et al 1991, V-7).

With respect to current resource development, there appears to be a consensus among this group of experts that the near future includes at least a few centuries; certainly no less than three centuries after closure or at least 3% of the full regulatory period.

3.6.2 Federal and State Plans for Full Resource Recovery

Within two miles of the area withdrawn for the WIPP, the WIPP is surrounded by forty eight sections of federal and state lands. These public lands are managed by either the U.S. Department of Interior or the State of New Mexico. These lands are within the Secretary's Boundary (U.S. DOI 1986) for the potash area. In addition to federal policy (U.S. DOI 1986) for the management of federal lands in the potash area, the management of the federal lands are also subject to the Federal Land Policy and Management Act (FLPMA 1989). The state lands are subject to state regulations protecting natural resources, specifically oil, gas, and potash (LeMay et al. 1988).

With respect to federal lands, it is the stated intent of the Secretary of Interior (U.S. DOI 1986) to "adequately protect the rights of the oil and gas, and potash lessees and operators," (U.S. DOI 1986, 39425). FLPMA intends for "the public lands to be managed in a manner which recognizes the nation's need for domestic sources of minerals, food, timber, and fiber..." (FLPMA 1989, §1702(12)). In addition, FLPMA requires the management of federal lands "be on the basis of multiple use and sustained yield unless otherwise specified by law" (FLPMA 1989, §1701 (7)). "The term multiple use means the management of the public lands and the various resource values so that they are utilized in the combination that will best meet the present and ***future needs*** [emphasis added] of the American people" (FLPMA 1989, §1702(c)). The term multiple use also means "a combination of balanced and diverse resource uses that take into account the ***long-term needs of future generations*** [emphasis added] for renewable and nonrenewable resources...." Sustained yield is defined as "the achievement and management ***in perpetuity*** [emphasis added] of a high-level annual or regular periodic output of the various renewable resources of the public land consistent with multiple use" (FLPMA 1989, §1702(h)). By federal law, human activities in the resource rich areas surrounding the WIPP do not appear to be not limited to the ***near future*** and are not limited to ***the expected use of existing leases.***

The objective of the rules and regulations of the state of New Mexico "is to prevent waste, protect correlative rights, assure maximum conservation of the oil, gas and potash resources of New Mexico, and permit the economic recovery of oil, gas, and potash minerals in the area hereinafter defined" (LeMay et al. 1988).

It is the policy and plans of both federal and state law to promote resource production on these public lands adjacent to the WIPP Land Withdrawal Area. None of the public lands adjacent to the WIPP have been withdrawn from resource development. Hence, the DOE application should assume that potash, crude oil, and natural gas will be allowed to be fully developed, including fluid injection activities necessary for resource recovery.

3.6.3 Oil and Gas Resources

In addition to the oil and gas reserves estimated by Broadhead et al. (1995), the application should also reflect that oil and gas reserves have not yet been quantified on many sections surrounding the WIPP site due to the U.S. Department of Interior and the State of New Mexico restrictions on drilling for petroleum in the potash deposits (U.S. DOI 1986; LeMay et al. 1988). Fifteen sections within the two mile band surrounding the WIPP do not have a single oil and/or gas well drilled into them. Or in terms of forty-acre units, of the 768 forty-acre units within two miles of the WIPP Boundary, 652 of the units do not yet have any oil or gas wells. In other words, 85% of the area immediately surrounding the WIPP has yet to be directly tested for oil and gas. The oil and gas leases in many of these areas have been assigned, but permission to drill has been denied and/or is in litigation (Burski 1994). Similarly, potash reserves are in litigation (Parker 1993) or have yet to be assigned although at least one potash company has stated that it intends to mine these reserves on public land (Morehouse 1995).

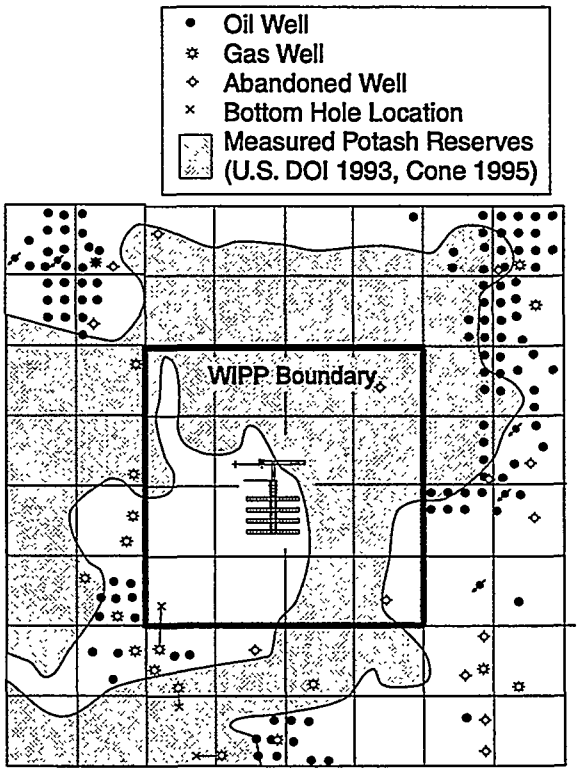


Figure 3-20. Actual oil, gas and injection well boreholes.

The nature of any resource recovery activity, including the oil and gas business, is such that today's non-economical resources often represent tomorrow's producible reserves. The application for a 10,000 year repository should reflect

an understanding of that principle of natural resource economics and can not limit itself to a simple assumption of current economic value. And as emphasized in the executive summary of the 1995 natural resources study (NMBM&MR 1995), the discovery of reserves of oil and gas can hinge simply on a better interpretation of well logs. Hence, current estimates of oil and gas resources reflect, to some extent, the limits of the current interpretation of well logs. Due to the nature of oil and gas production, as practiced throughout southeastern New Mexico, throughout the Delaware Basin, and in the vicinity of the WIPP, the existing federal plans and state plans inherently include salt water disposal and waterflooding throughout each and every federal and state section surrounding the WIPP Site.

3.6.4 Fluid Injection for 10,000 Years

The DOE application may need to consider fluid injection adjacent to the site and within the site for the full 10,000 year period. In the 1991 DOE elicitation of expert opinion on future activities in the vicinity of the WIPP, only one of four teams addressed fluid injection. This team was aware of the need to dispose of waste brine associated with oil production (Gordon et al. 1990, C-29), but was not aware of the extent of drilling for crude oil in the vicinity of the WIPP (Silva 1994, 28-35). Hence, the elicitation panel concluded that the current level of industrial activity in the WIPP area to be low (Hora et al. 1991, IV-10). Nonetheless, three members of the this team assigned probabilities for injection of waste brine associated with other industrial activities for the full 10,000 years. Further, the probability of a larger number of such injection wells was predicted to increase with time for the full 10,000 year period (Hora et al. 1991, Table IV-16).

3.6.5 Areal Extent of Delays in Oil and Gas Production

As to potential delays in oil and gas production and fluid injection due to the presence of minable potash, that issue is still in deliberation (Burski 1994).

Furthermore, there appears to be some disagreement as to what constitutes minable potash. The estimates of potash resources prepared by Griswold (1995a) for the New Mexico Bureau of Mines and Mineral Resources acknowledges federal policy but uses an economic limit which is different from federal policy, resulting in minable areas substantially smaller than federal policy. Cone (1995) later cautioned Griswold about BLM policy and experience. Griswold (1995b) subsequently acknowledges that his interpretation of the estimated extent of potash reserves is "conservative." According to Cone (1995), the federal position for minable potash is 4 feet by 10% for sylvite ("40" contour) and 4 feet 4% for langbeinite ("16" contour). Hence, the federal position on the actual area of minable potash, which could impact the near future activity of oil field production and fluid injection, is significantly larger than that mapped by the "55" contour for sylvite and the "37.5" contour for langbeinite in the natural resources study by the New Mexico Bureau of Mines and Mineral Resources (1995). Drilling for oil and gas may be delayed over a much larger area, thus extending the time for such near future activities.

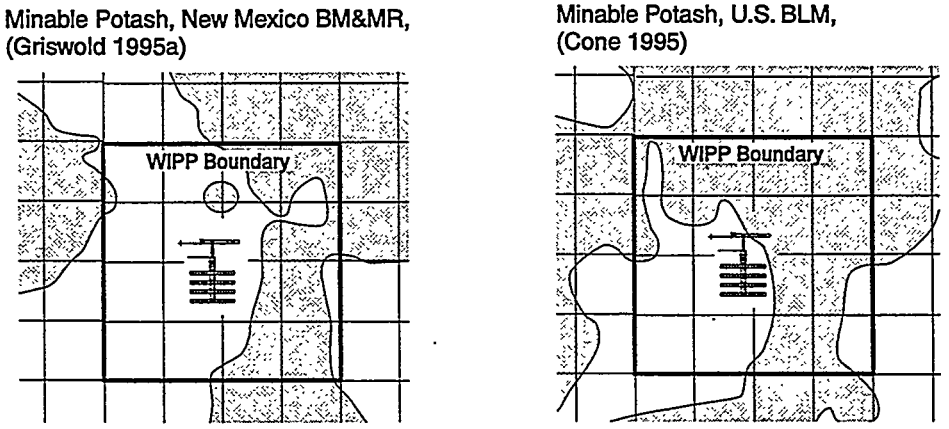


Figure 3-21. Areal extent of minable potash as determined by U.S. BLM and New Mexico Bureau of Mines and Mineral Resources.

3.6.6 Enhanced Oil Recovery by Carbon Dioxide or Gas Injection

The DOE application is sponsoring a new research effort that is exploring the use of pressure maintenance programs and advanced reservoir management to improve oil recovery from fourteen sands in the Brushy Canyon and Cherry Canyon members of the Nash Draw Unit (Strata Production 1996) in the potash enclave. One goal is to transfer the technology to oil and gas producers throughout the Permian Basin. The Department of Energy is sponsoring the project at an annual budget of 1.8 million dollars. The permeabilities in the sands are relatively low, ranging from 0.5 to 18 millidarcies. Although not stated in the progress report (Strata Production 1996), the low permeabilities strongly suggest that it may be necessary to inject a low viscosity fluid such as carbon dioxide or natural gas. Presumably, the Department of Energy is investing in this project, in the Delaware Basin, with the anticipation that such fluid injections will improve oil recovery. The DOE WIPP application should reflect this effort to enhance oil recovery in Delaware sands.

3.6.7 Summary

In summary, the DOE WIPP application to EPA can assume that for crude oil, there will be drilling on a minimum of forty acre spacings in the areas in litigation. There will also be drilling on a minimum of forty acre spacing in areas identified by Broadhead et al., (1995) known to contain proven and probable oil reserves, and there will be drilling into the fifteen yet to be explored sections within two miles of the WIPP. The extent of oil and gas resources remain to be determined. Experience has also shown that additional reserves are often discovered as a result of improvement in well log interpretation (NMBM&MR 1995). The DOE application needs to demonstrate an understanding of the economics of resource recovery and the concept of future reserves, an understanding of federal and state policy and plans regarding resource recovery on public lands, including pressurized fluid injection, an understanding of how

pressurized fluids can transport radionuclides to the accessible environment, and an understanding that the EPA intends that the repository curb the release of radionuclides to the accessible environment for a 10,000 year regulatory period, not just the near future. The application can realistically anticipate that salt water disposal activities and waterflooding, as practiced in the Delaware Basin and in southeast New Mexico, will take place throughout the area surrounding the WIPP. The application needs to consider other fluid injection, such as gas pressure maintenance, and needs to anticipate industrial waste injection over the full 10,000 year life of the repository.

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5. LIST OF ACRONYMS

ANPR	Advance Notice of Proposed Rulemaking
APD	Applications for Permit to Drill
BBL	Barrels
BLM	Bureau of Land Management
CAO	Carlsbad Area Office
CARD	Citizens for Alternatives to Radioactive Dumping
CFR	Code of Federal Regulations
DCCA	Draft Compliance Certification Application
DOE	U.S. Department of Energy
DOI	Department of Interior
EEG	Environmental Evaluation Group
EPA	U.S. Environmental Protection Agency
ERDA	Energy Research and Development Administration
FEP	Features, events, and processes
FLPMA	Federal Land Policy and Management Act
GAO	U.S. Government Accounting Office
GPM	Gallons per minute
MOU	Memorandum of Understanding
MPa	Megapascal
NAS	National Academy of Science
NMBM&MR	New Mexico Bureau of Mines and Mineral Resources
NMEMD	New Mexico Energy and Minerals Department
NMEMNRD	New Mexico Energy, Minerals, & Natural Resources Department
NMOCD	New Mexico Oil Conservation Division
NMPM	New Mexico Principal Meridian
OCD	New Mexico Oil Conservation Division
PA	Performance Assessment
PCs	Personal computers

LIST OF ACRONYMS (continued)

PSI	Pounds per square inch
RCRA	Resource Conservation and Recovery Act
SAR	Safety Analysis Report
SC&A	Sanford Cohen and Associates
SNL	Sandia National Laboratories
SWD	Salt water disposal
SRIC	Southwest Research and Information Center
TA	Temporarily Abandoned
TRU	Transuranic
USCA	United States Code Annotated
U.S. EPA	U.S. Environmental Protection Agency
U.S.G.S	U.S. Geological Survey
U.S. GAO	U.S. Government Accounting Office
VOC	Volatile organic compound
WIPP	Waste Isolation Pilot Plant

6. LIST OF WORKSHOP ATTENDEES

Rip Anderson	SNL
Bob Andrews	NAS/NRC
David Back	SC&A
James Barker	NMBM&MR
Bill Bartlett	EEG
Rick Beauheim	SNL
Sarah Bigger	CAO
Bob Bills	DOE
Deirdre Boak	SNL
Ron Broadhead	NMBM&MR
Chuck Byrum	EPA
Rafael Casanova	EPA, Region 6
David Catanach	NMOCD
Jim Channell	SC&A
Lokesh Chaturvedi	EEG
Dwight Deal	IT
George Dials	DOE/CAO
Kevin Donovan	Westinghouse
Lori Dotson	SNL
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Don Hancock	SRI
Garland Harris	CARD
Susan Hirshberg	CCNS
Mike Irwin	SNL
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Robert Neill	EEG
James Olsen	BLM
John Parker	NMED
Tom Peake	EPA
Dennis Powers	Consultant
Joe Ramey	Self
Les Shephard	SNL
Matthew Silva	EEG
Dan Stoelzel*	SNL
Ben Stone	NMOCD
Bill Stone	NMED
Peter Swift	SNL
Bill Thompson	WTAC
Tim W. Gum	NMOCD
Cooper Wayman	DOE/CAO
Wendell Weart	SNL
Chris Wentz	NMEMNRD
Steve Zappe	NMED

*Did not sign in

7. LIST OF EEG REPORTS

EEG-1 Goad, Donna, A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, June 1979.

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al, (eds.) Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, August 1979.

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EEG-11 Channell, James K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

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SEE COMMENTARY

Assessing dangerous climate change through an update of the Intergovernmental Panel on Climate Change (IPCC) ''reasons for concern''

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Article 2 of the United Nations Framework Convention on Climate Change [United Nations (1992) http://unfccc.int/resource/docs/convkp/conveng.pdf. Accessed February 9, 2009] commits signatory nations to stabilizing greenhouse gas concentrations in the atmosphere at a level that ''would prevent dangerous anthropogenic interference (DAI) with the climate system.'' In an effort to provide some insight into impacts of climate change that might be considered DAI, authors of the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) identified 5 ''reasons for concern'' (RFCs). Relationships between various impacts reflected in each RFC and increases in global mean temperature (GMT) were portrayed in what has come to be called the ''burning embers diagram.'' In presenting the ''embers'' in the TAR, IPCC authors did not assess whether any single RFC was more important than any other; nor did they conclude what level of impacts or what atmospheric concentrations of greenhouse gases would constitute DAI, a value judgment that would be policy prescriptive. Here, we describe revisions of the sensitivities of the RFCs to increases in GMT and a more thorough understanding of the concept of vulnerability that has evolved over the past 8 years. This is based on our expert judgment about new findings in the growing literature since the publication of the TAR in 2001, including literature that was assessed in the IPCC Fourth Assessment Report (AR4), as well as additional research published since AR4. Compared with results reported in the TAR, smaller increases in GMT are now estimated to lead to significant or substantial consequences in the framework of the 5 ''reasons for concern.''

Article 2 | UNFCCC | climate change impacts

Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) commits signatory nations to stabilizing greenhouse gas concentrations in the atmosphere at a level that ''would prevent dangerous anthropogenic interference (DAI) with the climate system.'' The UNFCCC also highlights 3 broad metrics with which decision-makers are to assess the pace of progress toward this goal: allow ''ecosystems to adapt naturally to climate change,'' ensure that ''food production is not threatened,'' and enable ''economic development to proceed in a sustainable manner.'' In an effort to provide some insight into impacts that might be considered DAI, authors of the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) identified 5 ''reasons for concern'' (RFCs) in (1). Each RFC categorizes impacts of a similar type, providing a set of metrics reflecting severity of risk. Relationships between various impacts reflected in each RFC and increases in global mean temperature (GMT) were portrayed in what has come to be called the ''burning embers diagram''; the image was also included in the Summary for Policy Makers of the contribution of Working Group II to the TAR and highlighted in the Synthesis Report.

In presenting the ''embers'' in the TAR, IPCC authors did not assess whether any single RFC was more important than any other; nor, as they noted, did they conclude what level of impact or what atmospheric concentrations of greenhouse gases would constitute DAI, a value judgment that would be policy-prescriptive. The ''embers'' were designed primarily to communicate the associations of impacts with increases in GMT and facilitate examination of the underlying evidence for use by decision-makers contemplating responses to these concerns.

The IPCC Fourth Assessment Report (AR4) states that ''the 'reasons for concern' identified in the TAR remain a viable framework for assessing key vulnerabilities'' (2). In this article, we revise sensitivities of the RFCs to increases in GMT, based on our expert judgment about new findings in the growing literature since the publication of the TAR in 2001.* Furthermore, our judgments are supported by a more thorough understanding of the concept of vulnerability that has evolved over the past 8 years,† as well as a more careful articulation of the criteria by which any specific vulnerability can be labeled ''key,'' and thus contribute to a reason for concern (3).‡

Section 1 defines and reviews the RFCs and ''burning embers'' figure as presented in the IPCC TAR. Section 2 presents the

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*These judgments were vetted by 3 rounds of IPCC review and were approved in the Summary for Policymakers of both the AR4 Working Group 2 and Synthesis Reports by the IPCC Plenary.

†Vulnerability to climate change is the degree to which geophysical, biological and socioeconomic systems are susceptible to and unable to cope with adverse impacts of climate change.

‡The criteria are: (*i*) magnitude of impacts; (*ii*) timing of impacts; (*iii*) persistence and reversibility of impacts; (*iv*) potential for adaptation; (*v*) distributional aspects of impacts and vulnerabilities; (*vi*) likelihood (estimates of uncertainty) of impacts and vulnerabilities and confidence in those estimates; and (*vii*) importance of the system(s) at risk. IPCC authors applied only the first 6 criteria in its assessment, because ''importance'' is really a subjective judgment by a potential decision-maker and thus crosses too far into the realm of being ''policy prescriptive''; we follow the same convention.

ENVIRONMENTAL SCIENCES

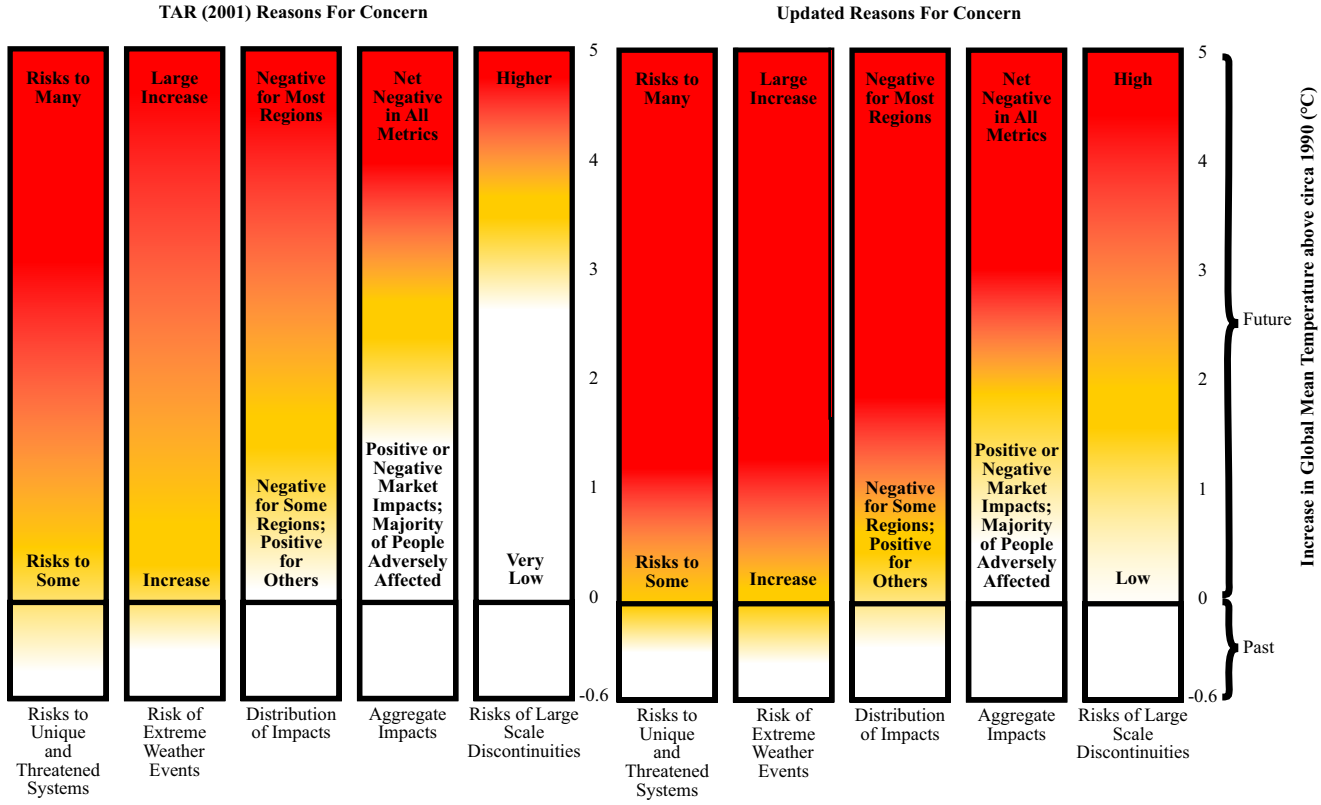


Fig. 1. Risks from climate change, by reason for concern—2001 compared with updated data. Climate change consequences are plotted against increases in global mean temperature (°C) after 1990. Each column corresponds to a specific RFC and represents additional outcomes associated with increasing global mean temperature. The color scheme represents progressively increasing levels of risk and should not be interpreted as representing ''dangerous anthropogenic interference,'' which is a value judgment. The historical period 1900 to 2000 warmed by ≈0.6 °C and led to some impacts. It should be noted that this figure addresses only how risks change as global mean temperature increases, not how risks might change at different rates of warming. Furthermore, it does not address when impacts might be realized, nor does it account for the effects of different development pathways on vulnerability. (*A*) RFCs from the IPCC TAR as described in section 1. (*B*) Updated RFCs derived from IPCC AR4 as supported by the discussion in section 2. (Reproduced with permission from Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Figure SPM-2. Cambridge University Press.)

update of the RFCs and the "burning embers" figure derived from the recently released IPCC AR4 and subsequent literature. The final section compares the earlier representation with the updated version.

The IPCC TAR and Reasons for Concern. Fig. 1 *Left* replicates the version of the "burning embers" diagram that was offered as figure SPM-2 in the Summary for Policymakers of the contribution of Working Group II to the TAR (4). IPCC AR4 projected a range of 1.1 °C to 6.4 °C increase in GMT from 1990 to 2100 (5) based on 6 IPCC Special Report on Emissions Scenarios (SRES) nonmitigation scenarios (6). Although uncertainty in the response of the climate system to increasing greenhouse gas concentrations contributes to this very broad spread in projections of increase in GMT, the magnitude of future emissions driven by alternative development pathways plays a comparable role. The assessed "likely range" (66–90%) of global temperature increase by 2100 for the lowest emissions scenario (SRES B1) is 1.1 °C to 2.9 °C, whereas the likely range for the highest scenario (SRES A1FI) is 2.4 °C to 6.4 °C. Since 2000, the trajectory of global emissions is above the highest SRES scenario (5). The observed temperature change, reflecting the response to date of the climate system to historical emissions, is also at the top of the projected range of temperature increase (7). The temperature increases in Fig. 1 go up to 5 °C although, as the IPCC projects, the increase in GMT could exceed 5 °C by 2100. An increase in GMT >5 °C by 2100 would have even more adverse effects within each RFC than has been analyzed.

The right side of Fig. 1 tracks the updated 5 RFCs against increases in GMT above 1990.[§]

Risk to Unique and Threatened Systems. This RFC addresses the potential for increased damage to or irreversible loss of unique and threatened systems, such as coral reefs, tropical glaciers, endangered species, unique ecosystems, biodiversity hotspots, small island states, and indigenous communities.

Risk of Extreme Weather Events. This RFC tracks increases in extreme events with substantial consequences for societies and natural systems. Examples include increase in the frequency, intensity, or consequences of heat waves, floods, droughts, wildfires, or tropical cyclones.

Distribution of Impacts. This RFC concerns disparities of impacts. Some regions, countries, and populations face greater harm from climate change, whereas other regions, countries, or pop-

[§]It is recognized that vulnerability can also be partly a function of the expected rate of climate change, but this assessment focuses on the magnitude of change. These magnitudes are, however, projected to occur over time frames that imply rates of change that are very likely to exceed the abilities of natural and human systems to adapt completely.

ulations would be much less harmed—and some may benefit; the magnitude of harm can also vary within regions and across sectors and populations.

Aggregate Damages. This RFC covers comprehensive measures of impacts. Impacts distributed across the globe can be aggregated into a single metric, such as monetary damages, lives affected, or lives lost. Aggregation techniques vary in their treatment of equity of outcomes, as well as treatment of impacts that are not easily quantified. This RFC is based mainly on monetary aggregation available in the literature.

Risks of Large-Scale Discontinuities. This RFC represents the likelihood that certain phenomena (sometimes called singularities or tipping points) would occur, any of which may be accompanied by very large impacts. These phenomena include the deglaciation (partial or complete) of the West Antarctic or Greenland ice sheets and major changes in some components of the Earth's climate system, such as a substantial reduction or collapse of the North Atlantic Meridional Overturning Circulation (8).

The RFCs were selected based on literature and judgments of the authors about risks from climate change. As indicated in the caption to Fig. 1, the authors made judgments for each RFC about what increases in GMT above 1990 would be associated with neutral or low impacts or risks (Fig. 1, white regions), negative impacts for some systems or more significant risks (Fig. 1, yellow regions), and substantial negative impacts or risks that are more widespread and/or severe (Fig. 1, red regions). In every case, the number of impacts and the harm implied depended on the rate of climate change, the amount of climate change, and the vulnerability of the affected systems. However, no single metric could adequately describe the diversity of impacts and associated risks for any one RFC, let alone aggregate across all of them into a single "dangerous" global temperature threshold. Within each RFC, therefore, multiple metrics were aggregated through expert judgment, and no aggregation was attempted across the RFCs. Moreover, it was clear that an objective ranking of relative importance across the RFCs would be impossible.

The various shadings and the judgments they depict only took autonomous adaptation into account (i.e., adaptation that might be expected to occur in the absence of anticipatory policies and measures), to the extent that such responses were captured by the underlying literature. The impacts literature, however, often makes simplifying assumptions about adaptation which can result in overestimates or underestimates of the magnitude of negative or beneficial impacts. Furthermore, there is little information on the effects of proactive adaptation (i.e., adaptations implemented to anticipate and lessen the adverse impacts of climate change, such as breeding new crop varieties or planning for coastal protection) in reducing vulnerability. Thus, it is uncertain how the relationship between the RFCs and increase in GMT would be affected by consideration of proactive adaptation.

In summary, the first 2 RFCs—Risks to Unique and Threatened Systems and Risks to Extreme Events—were judged in the TAR to imply substantial impacts or risks (transition from yellow to red) between 1 °C and 2 °C above 1990 levels. The third and fourth RFCs—Distribution of Impact and Aggregate Impacts—reflected substantial risks beginning in the range between 2 °C and 3 °C. The fifth RFC—Risks of Large-Scale Discontinuities—was not judged to be a source of substantial risk until GMT climbed more than 4 °C or 5 °C above the 1990 mean.

Updating the Reasons for Concern After the IPCC AR4. Fig. 1 *Right* shows the results of our assessment based on literature since the TAR. In updating the "embers," we retained the same color scheme and structure as the TAR. The same scale for temperature change frames the update. Transitions between colors remain fuzzy because there was (and there still is) uncertainty about the increase in GMT associated with a transition from little or no risk to some risk and from some to substantial and/or widespread risk for any specific system or sector. As was true in the TAR, the aggregation of risk across many different sectors, regions, or populations under a particular RFC is subjective, and thereby introduces another source of uncertainty. The width and placement of the transitions in each bar can nonetheless still be interpreted as visual representations of aggregated damage functions for each RFC, with narrower and lower transitions representing rapidly changing levels of risk as a function of temperature.

We take each RFC in turn in this update. Our assessment of risk for each is based on not only new information about impacts and vulnerabilities assessed in the AR4 and since, but also more clearly established criteria for identifying "key vulnerabilities" (3).

Risks to Unique and Threatened Systems. There is new and stronger evidence since the TAR of observed impacts of climate change on unique and threatened systems (such as polar and high mountain communities and ecosystems), with increasing levels of adverse impacts as temperatures increase further. An increasing risk of species extinction and coral reef damage is projected with higher confidence than in the TAR. There is medium confidence that ≈20–30% of known plant and animal species are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5 °C to 2.5 °C over 1980–1999 levels ("1990 levels" hereafter), a finding not made in the TAR (9). Confidence has increased that a 1 °C to 2 °C increase in GMT above 1990 levels poses significant risks to many unique and threatened systems, including many biodiversity hotspots. Corals are vulnerable to thermal stress and may have limited adaptive capacity. Increases in sea surface temperature of ≈1 °C to 3 °C are projected to result in more frequent coral bleaching events and widespread mortality unless there is substantial thermal adaptation or acclimatization by corals (10, 11). Increasing vulnerability of Arctic indigenous communities and small island communities to warming has been observed and is projected to accelerate (12). Kurz *et al.* (13) found that outbreaks of mountain pine beetle in British Columbia linked to climate change have resulted in net loss of forest biomass.

On the basis of this evidence, particularly the emergence of a number of adverse impacts that are clearly linked to anthropogenic climate change, the yellow shading in the leftmost bar of Fig. 1 *Right* begins the transition to red slightly above 0 °C, indicating substantial impacts and/or moderate risks at current temperature levels. The darker red shading, indicating potentially severe and/or widespread impacts and associated increases in risks, begins to appear ≈1 °C.

Risks of Extreme Weather Events. It is now more likely than not that human activity has contributed to observed increases in heat waves, intense precipitation events, and the intensity of tropical cyclones (2). There are, as well, more observations of climate change impacts from extremes than in the TAR (5, 14). Responses to some recent extreme climate events have also revealed higher levels of vulnerability across the globe, producing significant loss of life and property damage in both developing and developed countries. The large and unexpected health impacts due to a heat wave of unprecedented magnitude in 2003 in Europe provide one such example (15).¶ Projected increases

¶Schär *et al.* (15) found that the likelihood of the 2003 heat wave in Europe, which led to the death of tens of thousands of people, was substantially increased by increased greenhouse gas concentrations compared with preindustrial levels and associated regional mean temperature increase. Luterbacher *et al.* (31) come to a similar conclusion based on a complementary line of inquiry despite working with a shorter estimated return period.

in the intensities of tropical cyclones, droughts, extreme heat waves, and floods would further increase risks to human life, damage to property and infrastructure, and damage to ecosystems, and there is now higher confidence than in the TAR in the projected increases in these events as well as their adverse impacts. More specifically, increases in drought, heat waves, and floods are projected in many regions and would have adverse impacts, including increased water stress, wildfire frequency, and flood risks (starting at less than 1 °C of additional warming above 1990 levels) and adverse health effects (slightly above 1 °C) (2).

Risk is the product of probability and consequence. The more extensive projections of increasing frequency and intensity of extreme weather events with warming (5), combined with the conclusions that severe impacts from such extreme weather events are already apparent (12), suggest that the temperature levels associated with yellow and red gradations of risk begin ≈0 °C and just below 1 °C in the second bar of Fig. 1 *Right*, respectively. Lowering the yellow-to-red transition is justified in some cases by increases in the likelihood of extreme events, by the increased impacts at a given GMT in other cases, and by a combination of these in other examples.

Distribution of Impacts (and Vulnerabilities). As in the TAR, the AR4 found that vulnerability is distributed unevenly across the globe. There is increased evidence that low-latitude and less-developed areas generally face greater risk than higher-latitude and more-developed countries, because of both higher sensitivity and lower adaptive capacity; for example, in dry regions and mega-deltas (2, 16). There is new evidence, some of it coming from observed impacts, that vulnerability to climate change is also highly variable within individual countries, including developed countries (17). There is increasing evidence of greater vulnerability of specific populations, such as the poor and elderly, to climate variability and change in not only developing but also developed countries, and that high levels of adaptive capacity may not be realized in practice in the face of stress. For example, events such as Hurricane Katrina[‖] and the 2003 European heat wave have shown that the capacity to adapt to climate-related extreme events is lower than expected and, as a result, their consequences and associated vulnerabilities are higher than previously thought.

It is also now possible to better identify specific systems, sectors, and regions across the globe that are particularly vulnerable. There are sharp differences across the globe, in large measure because those in the weakest economic position are often the most vulnerable to climate change and are frequently the most susceptible to climate-related damages. This is especially true when they face multiple stresses; it is also now recognized that climate change can, itself, be the source of multiple stresses. New studies confirm that Africa is one of the most vulnerable continents because of the range of projected impacts, multiple stresses, and low adaptive capacity (18). For these reasons, and because IPCC AR4 (12) show many of the noted vulnerabilities begin or continue to grow with increases in GMT of less than 1 °C, the yellow shading begins below 1°C in the third bar of Fig. 1 *Right*, and the red shading emerges between 1 °C and 2°C.

Net Aggregate Impacts. Initial net market-based benefits from climate change are now projected to peak at lower magnitudes of temperature increase than in the TAR. It is likely that there will be higher damages for larger magnitudes of increased GMT, and the net costs of impacts of warming are projected to increase over time. Recent studies have estimated potential damages from increased extreme weather events (19, 20, 32). Inclusion of these impacts in aggregation could substantially reduce net aggregate benefits and lower the GMT increase at which net aggregate benefits peak (i.e., marginally decline) or at which they become negative. In addition, different analytic techniques (21) result in estimates of higher net damages, and inclusion of indirect effects can increase the magnitude of impacts (22, 23).

Aggregate impacts have also been quantified in nonmonetary metrics. For example, climate change over the next century is likely to adversely affect hundreds of millions of people through increased coastal flooding after a further 2 °C warming from 1990 levels (16); reductions in water supplies (0.4 to 1.7 billion people affected with less than a 1 °C warming from 1990 levels; ref. 24); and increased health impacts (that are already being observed; ref. 25).

As a result of uncertainties and use of different metrics, it is difficult to place transitions between the colors for aggregate impacts in the figure. In the revision of the figure, the fourth bar in Fig. 1 *Right* shows the yellow shadow beginning just ≈1 °C because of projections of the number of people adversely affected by climate change. The transition to red is difficult to place because it can vary depending on the metrics that are used. The transition should be no higher than just above 2 °C because of our conclusion about lower net market-based benefits. Application of nonmonetary metrics could justify a transition to red at a lower GMT.

Risks of Large-Scale Discontinuities.** There is very high confidence that global warming over many centuries would lead to a sea level rise contribution from thermal expansion alone (with associated loss of coastal area and other impacts) that is projected to be much larger than the observed contribution from expansion over the 20th century (26). There is now better understanding that the risk of additional contributions to sea level rise from melting of both the Greenland and possibly Antarctic ice sheets may be larger than projected by ice sheet models assessed in the AR4, and that several meters of additional sea level rise could occur on century time scales (2, 7, 27, 28). Such risk arises in part from ice dynamical processes apparent in observations since the TAR but not fully included in ice sheet models assessed in AR4. New insights also come from recent paleoclimate studies (29). Complete deglaciation of the Greenland ice sheet would raise sea level by 7 m and could be irreversible. There is medium confidence that at least partial deglaciation of the Greenland ice sheet, and possibly the West Antarctic ice sheet, would occur over a period ranging from centuries to millennia for a global average temperature increase of 1–4 °C (relative to 1990 levels); this may cause an additional contribution to sea level rise of 4–6 m or more. The AR4 also discusses the consequences of ocean acidification due to increasing CO_2 concentration. However, impacts of acidifaction and other direct effects of higher CO_2 concentration on calcifying organisms have yet to be confidently observed in situ, and the CO_2 concentration thresholds for such impacts, if any, are uncertain. Finally, compared with the TAR, there is now more confidence in projections of the climate consequences of amplifying feedbacks in the carbon cycle (26, 30).

Taken together, the updated evidence on large-scale discontinuities is reflected by beginning the yellow shading ≈1 °C in the rightmost bar of Fig. 1 *Right*. Red shading begins ≈2.5 °C, the midpoint of the warming range cited above for partial deglaciation and the possible trigger for commitment to large-scale global impacts over multiple-century time scales. Given the

[‖]Although not attributed in the literature in whole or in part to anthropogenic climate change, Hurricane Katrina demonstrated that even developed nations face significant and inequitable risks from extreme events.

**The TAR assessed the risk of abrupt and/or irreversible changes under the rubric of large scale singularities or discontinuities, and this usage is retained here.

uncertainties over the impacts of ocean acidification and also in the relationship of temperature to CO_2 concentration, the lower limit could arguably be placed lower.

Comparisons of the Reasons for Concerns 8 Years After the IPCC TAR. Compared with results reported in the TAR, smaller increases in GMT are now estimated to lead to significant or substantial consequences in the framework of the 5 "reasons for concern." This conclusion is displayed most vividly by side-by-side comparison of the "embers" from the TAR and the updated assessment displayed in the 2 panels of Fig. 1. The transitions from yellow (moderately significant risks) to red (substantial or severe risks) for all of the RFCs are at lower GMT increases above 1990 compared with the location of the transitions in the TAR. In addition, for 3 RFCs—distribution of impacts, aggregate impacts, and large-scale discontinuities—the transition from white to yellow (i.e., no or little risk to moderately significant risk) also occurs at a lower GMT increase. The transition from white to yellow in the unique and threatened systems and extreme events RFCs occurs at a lower increase in GMT because there are more and stronger observations of climate change impacts. The temperature range that is in yellow and red on large-scale discontinuities is now much wider than in the TAR. In general, the figure provides a visual portrait of the conclusion that the temperature range from which a consensus definition of "dangerous anthropogenic interference" might be drawn is getting lower.

In summary, the shifting of risk transitions to lower GMTs is derived from assessment of (*i*) strengthened observations of impacts already occurring because of warming to date, (*ii*) better understanding and greater confidence in the likelihood of climatic events and the magnitude of impacts and risks associated with increases in GMT, (*iii*) more precise identification of particularly affected sectors, groups, and regions, and (*iv*) growing evidence that even modest increases in GMT above levels circa 1990 could commit[††] the climate system to the risk of very large impacts on multiple-century time scales.

[††]The term "commit" is used as in AR4 WGII and is derived from the possibility of crossing thresholds of irreversible change, but ones for which the actual impact may be substantially delayed.

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JIM WEST/ALAMY



Drums containing contaminated materials from the US nuclear-defence programme are stored at the Waste Isolation Pilot Plant in New Mexico.

Reassess New Mexico's nuclear-waste repository

Proposals to bury plutonium from nuclear weapons must address chemical interactions and intrusion risks, say **Cameron L. Tracy**, **Megan K. Dustin** and **Rodney C. Ewing**.

More than 600 metres below ground near Carlsbad, New Mexico, is the world's only operating deep geological repository currently accepting transuranic nuclear waste: that contaminated by elements heavier than uranium. The Waste Isolation Pilot Plant (WIPP), run by the US Department of Energy (DOE), is used to dispose of laboratory equipment, clothing and residues from the nation's nuclear-defence programme. In the past 15 years, around 91,000 cubic metres (equivalent to covering a soccer field to a depth of about 13 metres) of such transuranic waste, mostly of relatively low radiation levels, has been placed there.

The main contaminants are long-lived isotopes of plutonium (mainly plutonium-239, with a half-life of 24,100 years, and plutonium-240, with a half-life of 6,560 years) and shorter-lived isotopes of americium and curium. In rooms carved out of a 250-million-year-old salt bed, the waste is stored in hundreds of thousands of plastic-lined steel drums. The repository is now at about half of its planned capacity and is to be sealed in 2033.

The DOE is responsible for performing safety assessments to ensure that WIPP will not exceed limits on exposure to radioactivity, as set by the US Environmental Protection Agency (EPA), for 10,000 years.

But new demands are emerging. An arms-control agreement with Russia made in 2000 obliges the United States to dispose of 34 tonnes of plutonium from dismantled nuclear weapons[1]. Following the terms of the agreement, the United States planned to convert the material into a fuel — mixed (uranium and plutonium) oxide, or MOX ▶

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— to burn in commercial nuclear-power plants. But faced with soaring construction costs for a MOX fabrication facility at the Savannah River Site in South Carolina, the DOE has commissioned evaluations of alternatives[2].

The most recent report[3], published in August 2015, recommends burying the weapons' plutonium at WIPP. Judging the repository's performance to have been "successfully demonstrated", the DOE's Red Team expert panel proposes that the 34 tonnes of weapons plutonium can be added to WIPP once it has been diluted to low concentrations comparable to that of the transuranic waste at WIPP.

In fact, WIPP's safety record is mixed. On 14 February 2014, a burst drum released small quantities of plutonium and americium to the surface (with a radioactivity of around 100 millicuries, or 3.7 gigabecquerels)[4]. Airborne radioactive material reached the surface through the ventilation system and spread 900 metres from the repository's exhaust shaft. Twenty-one workers were exposed to low levels of radioactivity, the highest dose equivalent to that from a chest X-ray. Nine days earlier, smoke from a burning truck filled the underground workings and shaft, damaging mechanical, electrical and ventilation systems.

The DOE says that such accidents do not compromise the long-term performance of the repository. We agree that they need not — if lessons are learned. Our concern is not the events' severity but that they were unanticipated. These accidents illustrate how difficult it is to predict potential failures of such a disposal system over millennia. For example, assumptions about the repository's geochemistry or the likelihood of drilling into it can lead to underestimates of the risks.

Before expanding WIPP's plutonium inventory, the DOE must examine more carefully its safety assesment for performance that stretches to 10,000 years and beyond.

CULTURE OF COMPLACENCY

The 2014 radioactive leak at WIPP was caused by heat from a chemical reaction in a drum[4]. Plutonium-contaminated nitrate salts, a waste product of plutonium purification at Los Alamos National Laboratory (LANL) in New Mexico, reacted with an organic, wheat-based commercial cat litter used as an absorbent for liquid wastes. The heat popped the lid. Although sensors detected the released radioactivity and diverted exhaust air through filters, some radioactive material leaked through. WIPP operators sealed the leak in the filtration system and sealed off the room in which the leak occurred. The breached drum remains in the repository.

Analyses of the accidents[4] by the DOE have documented a lack of a 'safety culture' at WIPP. The facility's successful operation for 15 years had bred complacency. The failures were wide-ranging: in safety assessments, control of drum contents, installation and maintenance of equipment, and preparation for an accident. An investigation of the drum-packaging procedure, for example, found "no evidence that any type of technical evaluation occurred" when selecting the organic absorbent material, even though its incompatibility with nitrate salts had been raised at LANL during waste packaging[4].

From a systems-analysis perspective, the drum breach was a 'normal' accident[5] — a human mistake that led to a cascade of errors and breakdowns, exacerbated by a failure to enforce safety protocols. Complex technologies are prone to unanticipated failures that can progress quickly; examples include the 1979 Three Mile Island nuclear-plant meltdown in Pennsylvania and the 1986 Challenger space-shuttle explosion. Such accidents cannot be easily predicted, but a system designed with failure in mind can mitigate the risk.

"We cannot be certain that future inhabitants of the area will even know WIPP is there."

The WIPP accident can be taken as a positive — it presents an opportunity to learn. The DOE has aggressively identified its causes and implemented corrective actions; incompatible chemicals are no longer mixed in the drums. But once the repository is closed, its contents cannot be monitored or problems fixed. We cannot be certain that future inhabitants of the area will even know that WIPP is there. To put the timescales in perspective, agriculture was developed just over 10,000 years ago.

LONG-TERM SAFETY

WIPP's present safety assessment addresses two scenarios: first, undisturbed performance and, second, human intrusion, such as inadvertently drilling through the repository in search of oil and gas[6]. The first foresees that after closure, the salt into which the repository is built will deform and flow around the drums to encase the waste. The model assumes that no fluids, such as brine, are present and that the site remains geologically isolated. Although the drums will be crushed, the radioactive material will be locked in the dry, solid salt, with no way to release radioactivity to the biosphere. Reliance on the geological barrier is so great that the form and composition of the waste is assumed to be unimportant; it need not even be treated.

Human intrusion could release radioactivity to the environment[6]. Salt deposits, layered as sediments or as salt domes, are often associated with mineral and energy resources, such as potash and hydrocarbons — oil and gas. In southeastern New Mexico, exploration for and extraction of these fuels has led to extensive drilling in the Permian Basin, where WIPP is located.

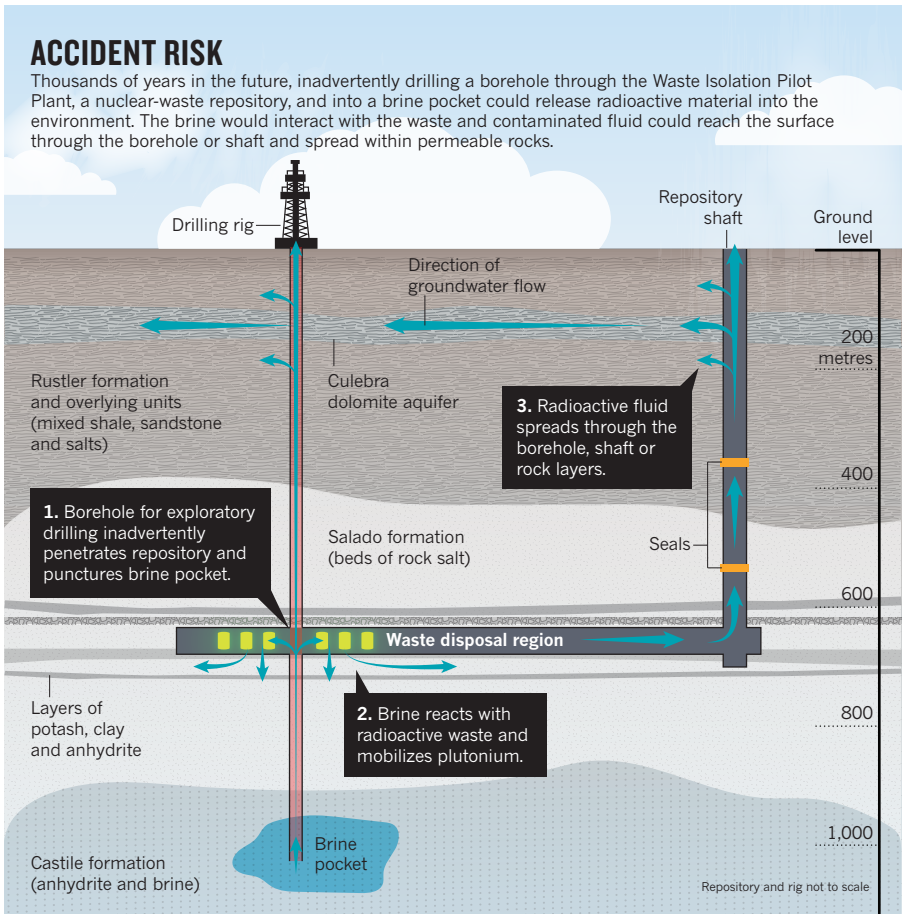
The probability of a borehole piercing the repository in the next 10,000 years is significant. If a borehole were to puncture the repository and a brine pocket, which are known to exist in the Castile geological formation below the Salado salt formation in which the repository sits, fluid may reach the transuranic waste (see 'Accident risk'). To assess the risk of radioactive release, one must first establish the probability of borehole penetration and determine how the pressurized brine will react with the waste.

In forecasting future drilling rates, the EPA has used a 100-year historical average rate for the region, which predicts 67.3 boreholes per square kilometre over the 10,000-year regulated period[6]. But drilling near WIPP has risen sharply in recent years. As horizontal drilling and hydraulic-fracturing techniques have made new areas of hydrocarbon-bearing rocks accessible, the Permian Basin has become the most prolific oil-producing area in the United States. A recent 10-year historical average (2002–12) yields 148 boreholes per square kilometre over 10,000 years, more than doubling the projected risk of repository intrusion. Drilling rates, the effects of new technologies, and supply and demand pressures on hydrocarbon production are difficult if not impossible to predict centuries ahead.

The concentration of transuranic elements leached by intruding brine is also hard to estimate because of the complexity of the waste: a typical drum contains a variety of materials, such as lab coats, gloves and other laboratory equipment. Different micro-geochemical environments will develop around different waste types. Chemically organic materials, such as plastic bags, may degrade by microbial action and generate carbon dioxide. In brine, CO_2 forms stable carbonate and bicarbonate complexes with plutonium and other actinides (elements 89–103), raising their concentrations in solution. Large bags of magnesium oxide powder, amounting to more than 31,000 tonnes, have been placed in WIPP disposal rooms as an 'engineered barrier'. The magnesium oxide should react with the CO_2 to form stable magnesium carbonates, thereby removing CO_2 from solution and reducing the solubility of actinides. This presumes that the reactions proceed to completion and all the CO_2 is consumed.

The safety analysis calculations for WIPP assume that there is no CO_2 present, dramatically lowering actinide concentrations in the brine and thus the risk of release of radioactivity. But reliance on magnesium oxide and a series of idealized reactions to constrain the repository's geochemistry is problematic, particularly if the amount of plutonium stored at WIPP increases. As made clear by the 2014 accidents, complex interactions of materials must be carefully considered when predicting the repository's

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performance now and in the future.

The Red Team report proposes diluting the weapons plutonium before its disposal in an "inert adulterant" — a classified mixture of cementing, gelling, thickening and foaming agents known as stardust. The report is unclear on what is meant by 'inert'; however, inert materials are rare, particularly those that must remain so for thousands of years.

PLUTONIUM DISPOSAL

In the case of plutonium-bearing solids, demonstrating chemical inertness presents a huge challenge. In near-surface conditions, plutonium can assume a variety of oxidation states — up to four, each with different solid-state and geochemical behaviours[7]. Its decay product uranium-235 has two principal oxidation states, U^{4+} and U^{6+}, each with different geochemical mobility[7]. This complexity makes it difficult to predict how the actinides will react or be transported.

Also, actinides decay mainly by the emission of α particles (energetic helium nuclei). During each decay, the daughter nucleus recoils and displaces thousands of atoms in the surrounding solid. Over time, this damage accumulates and changes the properties and chemical stability of the material. Radiation effects in actinide-bearing materials have been well documented over the past 20 years[8], but are not considered in the Red Team's evaluation.

The 'dilute-and-dispose' proposal to convert weapons-plutonium pits to plutonium oxide for burial in WIPP[3] immediately raises safety issues. The extra plutonium nearly triples the current projected plutonium (around 12 tonnes) at closure. The design and safety assessment did not envision such a large amount. WIPP's capacity would have to expand by 15%[1], increasing the likelihood that a borehole will one day intersect it.

And the changed inventory of actinides demands new assessments of interactions with the materials present, including brine and CO_2. The amount of plutonium mobilized in brine depends on its solubility, which depends on its form and the amount of CO_2 present after reaction with the bags of magnesium oxide.

NEXT STEPS

The current regulatory period of 10,000 years is short relative to the 24,100-year half-life of plutonium-239, let alone that of uranium-235, which has a half-life of 700 million years. To accommodate the extra plutonium, the regulatory period might be lengthened, meaning that the probability of human intrusion during this period increases.

Some of these issues and others were raised in two 2015 reviews[9,10] of the Red Team report by the consultancy High Bridge Associates of Greensboro, Georgia. But the analysis did not consider the possibility of human intrusion.

WIPP is fulfilling an important national need — the disposal of legacy transuranic waste from US defence programmes. Its opening was the culmination of 20 years of scientific research, engineering design and public engagement. Despite the accidents, WIPP can still fulfil its mission.

However, proposals to substantially increase the plutonium inventory combined with a failure to revise the safety assessment, particularly the possibility of human intrusion, bear witness to the ease with which policy decisions can disregard the fundamental science — and risk yet another failure.

The Red Team report shows a limited effort to consider or manage inherent risks. The shortcomings of proposals to dispose of weapons plutonium at WIPP mirror the operational failings that led to the 2014 accidents. Before the DOE considers implementing these recommendations, it should look to the repository's record over the past 15 years of operation and reassess its confidence in the safe performance of the facility over the next 10,000. ■

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Matters relating to science and review
The 2013–2015 review

Subsidiary Body for Implementation
Forty-second session
Bonn, 1–11 June 2015

Item 12 of the provisional agenda
The 2013–2015 review

Report on the structured expert dialogue on the 2013–2015 review

Note by the co-facilitators of the structured expert dialogue

Summary

This report summarizes the face-to-face dialogue between over 70 experts and Parties on: the adequacy of the long-term global goal in the light of the ultimate objective of the Convention; and the overall progress made towards achieving the long-term global goal, including a consideration of the commitments under the Convention. It includes a technical summary and a compilation of the summary reports on the four sessions of the structured expert dialogue (SED). The technical summary synthesizes the work done by the SED and includes 10 messages capturing the key findings from its sessions.

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I. Introduction

A. Mandate

1. At their forty-first sessions, pursuant to the mandate for a structured expert dialogue (SED) on the 2013–2015 review given in decision 1/CP.18, paragraph 86(b), the Subsidiary Body for Scientific and Technological Advice (SBSTA) and the Subsidiary Body for Implementation (SBI) requested the co-facilitators of the SED to prepare, with the assistance of the secretariat, a final factual report that includes a compilation and a technical summary of the summary reports on the meetings of the SED and to make it available no later than 3 April 2015.[1]

B. Scope of the report

2. This report summarizes the face-to-face dialogue between over 70 experts and Parties that took place between June 2013 and February 2015 on: the adequacy of the long-term global goal in the light of the ultimate objective of the Convention (theme 1 of the 2013–2015 review); and the overall progress made towards achieving the long-term global goal, including a consideration of the commitments under the Convention (theme 2 of the 2013–2015 review). It includes a technical summary of the work done by the SED, as well as the key findings from the SED meetings, as documented in the summary reports thereon. The technical summary features four sections: overarching considerations regarding the long-term global goal; theme 1 of the 2013–2015 review; theme 2 of the review; and consideration of strengthening the long-term global goal, referencing various matters presented by science, including in relation to the warming of 1.5 °C above pre-industrial levels. Annexes I–IV contain the summary reports on the four SED sessions. Annex V contains some statistics on the organization of the SED, while in annex VI, a list of experts who participated in the sessions of the SED can be found.

C. Possible action by the subsidiary bodies

3. The SBSTA and SBI are invited to consider this report in their deliberations on further steps to be taken in relation to the 2013–2015 review, including the recommendation of a draft decision for consideration and adoption at the twenty-first session of the Conference of the Parties (COP), pursuant to decisions 1/CP.16, paragraph 139(a), and 2/CP.17, paragraph 158.

D. Background

4. COP 16 recognized "that deep cuts in global greenhouse gas emissions are required according to science, and as documented in the *Fourth Assessment Report* of the Intergovernmental Panel on Climate Change, with a view to reducing global greenhouse gas emissions so as to hold the increase in global average temperature below 2 °C above pre-industrial levels, and that Parties should take urgent action to meet this long-term goal, consistent with science and on the basis of equity".[2] The COP also decided to periodically review the adequacy of this long-term global goal in the light of the ultimate objective of the Convention (theme 1 of the 2013–2015 review), and overall progress towards achieving

[1] FCCC/SBSTA/2014/5, paragraph 53, and FCCC/SBI/2014/21, paragraph 116.

[2] Decision 1/CP.16, paragraph 4.

the long-term global goal, including a consideration of the implementation of the commitments under the Convention (theme 2).[3] The 2013–2015 review was also tasked with the consideration of the strengthening the long-term global goal, referencing various matters presented by the science, including in relation to a temperature rise of 1.5 °C.[4]

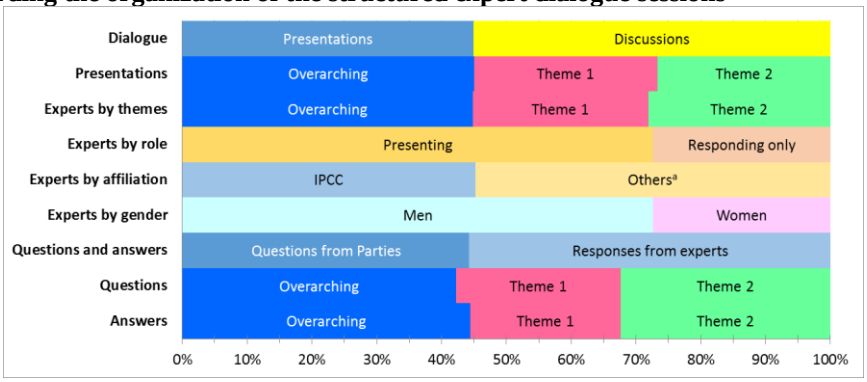
5. The COP carried out the 2013–2015 review with assistance from a joint SBSTA/SBI contact group. COP 18 established the SED to support the work of the joint contact group and ensure the scientific integrity of the review through a focused exchange of views, information and ideas.[5]

II. Technical summary – proceedings

6. The SED has held four sessions (five meetings) since its inception. These sessions were held in conjunction with sessions of the subsidiary bodies, and were open to all Parties and observers. The first session of the SED (SED 1) aimed to increase the understanding of existing scientific knowledge and explore how this knowledge could be used to address the two themes of the 2013–2015 review. SED 1 featured presentations by the World Meteorological Organization (WMO), the Intergovernmental Panel on Climate Change (IPCC) and the Hadley Centre for Climate Prediction and Research (HCCPR). The second session of the SED (SED 2) and the third session (SED 3) focused on the contributions of Working Groups I, II and III to the IPCC Fifth Assessment Report (AR5). The fourth session of the SED (SED 4) addressed the salient findings of the AR5, as reflected in its Synthesis Report; the key findings of reports prepared by United Nations agencies; the work done in relevant processes under the Convention; and regional and emerging information.

7. The SED sessions were organized as fact-finding, face-to-face exchanges of views between Parties and experts. The sessions were balanced in addressing the two themes of the review: an equal amount of time was allocated to each theme and both themes had similar formats (figure 1 and annex V). The organization of sessions took into account the 20 submissions of views from Parties and observer organizations.[6]

Figure 1
Statistics regarding the organization of the structured expert dialogue sessions



Note: "Overarching" connotes relevance to both themes of the 2013–2015 review.
Abbreviation: IPCC = Intergovernmental Panel on Climate Change.
[a] See paragraph 8 and annex VI for the affiliation of other experts.

[3] Decision 1/CP.16, paragraph 138.
[4] Decision 1/CP.16, paragraph 139(a)(iv).
[5] Decision 1/CP.18, paragraphs 85 and 86.
[6] Available at <http://unfccc.int/7590.php>.

8. Pursuant to decision 2/CP.17, paragraph 161, the SED considered:

(a) The contributions of all three working groups to the AR5, and its Synthesis Report;

(b) The work of following processes and bodies under the Convention: the Adaptation Committee, the Climate Technology Centre and Network (CTCN), the Green Climate Fund (GCF), the work of the SBI on capacity-building and Article 6 of the Convention, the Standing Committee on Finance (SCF) and the Technology Executive Committee (TEC);

(c) Reports of United Nations agencies and other organizations: the secretariat of the Convention on Biological Diversity (CBD), the Food and Agriculture Organization of the United Nations (FAO), the Global Environment Facility (GEF), the International Energy Agency (IEA), the United Nations Convention to Combat Desertification (UNCCD), the United Nations Environment Programme (UNEP), the World Health Organization (WHO), WMO and the World Bank;

(d) Reports of regional organizations, including: the Arctic Monitoring and Assessment Programme (AMAP), the Caribbean Community Climate Change Centre (CCCCC), CGIAR, HCCPR and the Secretariat of the Pacific Regional Environment Programme (SPREP).

9. Fifty-three experts made a total of 60 presentations, with more experts presenting on theme 2 than on theme 1. Twenty additional experts attended the sessions and participated in the discussions. Bearing in mind that the AR5 is the most comprehensive and robust assessment of climate change to date,[7] a majority of the experts invited were from the IPCC (30 experts). The work of the SED was also supported by experts from the Adaptation Committee, the CBD secretariat, CCCCC, CGIAR, the CTCN, the GCF, the GEF, IEA, the SCF, SPREP, the TEC, UNCCD, WHO, WMO and the World Bank (see annex VI). When inviting experts, the geographical, cultural and gender balance was taken into consideration.

10. A moderated discussion guided by 90 questions (see annex V) followed the presentations. Parties asked approximately 260 questions (with slightly more questions focusing on theme 2 than on theme 1) and received over 330 answers, with more than one expert answering each question, on average. Additionally, experts presenting in one part of the session also attended other parts, allowing for linkages to be made among the topics addressed. Some of the IPCC experts were present at all sessions of the SED, thereby ensuring the scientific integrity of the information discussed.

11. A summary report on each SED session was made available on the 2013–2015 review web page[8] (see annexes I–IV).

III. Technical summary – dialogue

12. The SED considered many findings and featured a great deal of discussion. This technical summary aims to document this very rich exchange by synthesizing the views of participating experts and Parties. In order to keep this summary succinct, we did not delve into details, which are available in the annexes, and synthesized the main points from the presentations and dialogue from the SED sessions.

13. This technical summary should be read with a number of caveats. It is not meant to present an exhaustive assessment of the issues at hand, as it is confined to documenting the

[7] Decision 12/CP.20, paragraph 3.

[8] <http://unfccc.int/7521.php>.

dialogue held. Furthermore, the views expressed by experts during the dialogue and captured here should not be seen as taking precedence over the findings of the AR5 or the reports from other organizations considered in SED sessions. We, the co-facilitators, made every effort to ensure that this technical summary is factual and reflects the scientific understanding of the issues addressed.

14. This section opens with a summary of the overarching considerations regarding the long-term global goal. It then addresses the following: the adequacy of the long-term global goal in the light of the ultimate objective of the Convention (theme 1 of the 2013–2015 review); the overall progress made towards achieving the long-term global goal, including a consideration of the commitments under the Convention (theme 2); and issues relating to a consideration of strengthening the long-term global goal, referencing various matters presented by the science, including in relation to a temperature rise of 1.5 °C.

A. Overarching considerations regarding the long-term global goal

15. Among the elements of the long-term global goal,[9] the SED addressed "reducing global greenhouse gas emissions" and "the increase in global average temperature below 2 °C above pre-industrial levels" (hereafter referred to as the limit for global warming), as well as the relationship between these elements. We first summarize the deliberations on the internationally agreed limit for global warming, and then those on the corresponding reduction in global greenhouse gas (GHG) emissions, given that this limit leads to an estimation of the budget of total cumulative anthropogenic carbon dioxide (CO_2) emissions and of the corresponding range of CO_2 equivalent (CO_2 eq) concentration levels in the atmosphere.[10] This in turns makes an estimation of the necessary reduction in global annual GHG emissions by mid-century possible (see paras. 21 and 22 below).

16. On the **global average temperature**, the IPCC reported an increase of 0.85 °C since 1880, a good approximation for pre-industrial levels (figure 2),[11] and WMO reported that 14 of the last 15 years were the warmest on record, with 2014 being the hottest.[12] More than 90 per cent of the energy accumulated in the climate system between 1971 and 2010 has been absorbed by the oceans, leading to their warming.[13] In terms of projections, for all representative concentration pathway (RCP) scenarios[14] of the IPCC, the global average temperature change is likely[15] to exceed 1.5 °C by 2100 relative to pre-industrial levels except for scenario RCP2.6.[16] For RCP4.5, warming is more likely than not to exceed 2 °C and will continue beyond 2100. The other RCP scenarios, which are closer to a 'business as usual' development, share these characteristics except that they are likely to exceed a

[9] See paragraphs 102–105 below on considerations relating to "taking action…on the basis of equity".

[10] See annex III, paragraphs 128–132, and figure 41 (note the probabilistic interpretation of scenarios that shows the relationship between atmospheric concentrations of CO_2 eq in 2100 and the probability of staying under 2 °C).

[11] See annex II, paragraph 18.

[12] El Niño played no part in the warming in 2014 (annex IV, paragraph 332, and figure 105). See also *WMO Statement on the Status of the Global Climate in 2014* (World Meteorological Organization. Available at <https://www.wmo.int/media/sites/default/files/1152_en.pdf>).

[13] See annex II, paragraph 19.

[14] Scenarios considered by the IPCC for projecting future climate conditions (see the summary for policymakers in the contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, box SPM.1. Available at <http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf>).

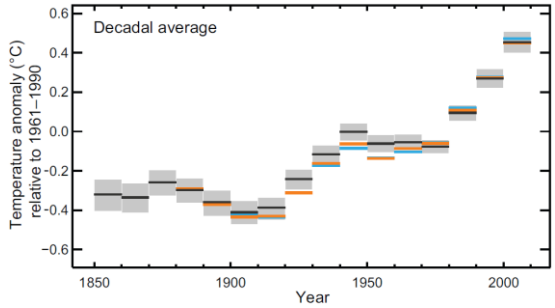
[15] For a definition of the uncertainty qualifiers used in this report, see footnote 1 to the summary for policymakers in the Synthesis Report of the AR5.

[16] See annex II, figure 15.

warming of 2 °C by 2100. Additionally, the IPCC reported that temperature changes will exhibit both inter-annual and decadal variability and regional differences (see, e.g., figure 3).[17] For example, regarding temperature extremes, heatwaves are expected to occur with higher frequency and duration.[18]

Figure 2

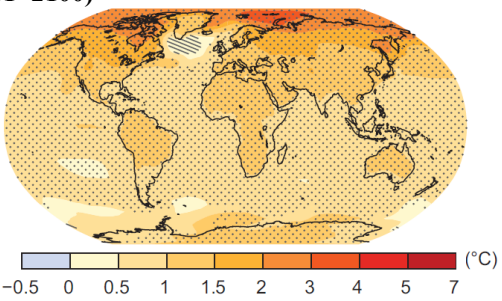
Observed global mean of combined land and ocean surface temperatures from 1850 to 2012, from three datasets



Source: Summary for policymakers in the contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.1(a).

Figure 3

Map of projected change in average surface temperature for RCP2.6 (1986−2005 to 2081−2100)



Source: Summary for policymakers in the contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.8.

Note: This map shows that even for a scenario with high mitigation action, future temperature changes vary among regions.

Abbreviation: RCP = representative concentration pathway.

17. The IPCC indicated that if a temperature limit were exceeded, which is sometimes referred to as an overshoot, warming could be returned to that limit in the longer term if the CO_2 content of the atmosphere is later actively reduced.[19] As for long-term aspects, an actual equilibrium in terms of temperature, notably of ocean waters, and sea level would only be reached after several centuries to millennia.[20] To a large extent, anthropogenic climate change, including ocean acidification and many impacts, are irreversible on at least a multi-century to millennial timescale.

18. **Parties sought clarification** on, inter alia: the reliability of short-term temperature projections, considering the reduced rate of warming over the last 15 years; uncertainties about the warmest year on record; committed temperature rise; the relationship between the timescale and physical changes in the climate system; and the limitations of working only with a temperature limit.

19. Experts explained that on a short timescale it remains difficult to predict when below or above average future warming would occur[21] and underscored the importance of using long-term temperature trends based on several decades (see also the trends of decadal averages in figure 2) instead of using only a few years when analysing the past.[22] They clarified that there is little warming commitment from past emissions in the physical climate system and that the future emissions determine future warming.[23] Despite the fact that any realized warming is basically irreversible, cutting emissions now has a swift effect

[17] See annex II, paragraph 33.
[18] See annex II, paragraph 34.
[19] CO_2 eq concentration overshooting the long-term stabilization level is typical for the scenarios limiting warming to 1.5 °C by the end of the century (see annex II, para. 60, and annex III, para. 132).
[20] See annex III, paragraph 59.
[21] See annex II, paragraph 24.
[22] See annex IV, paragraph 332.
[23] See annex II, paragraph 69.

by slowing down further warming within a few years. Moreover, actively removing CO_2 from the atmosphere, for example by using bioenergy with carbon capture and storage (BECCS),[24] results in cooling. They explained, however, that the timescale of physical changes depends on the type of changes (e.g. warming will immediately impact precipitation or extreme weather, whereas changes in the Greenland ice sheet melting or sea level rise would take much longer to occur). With respect to overshooting, the timescales for which the carbon budget for the long-term global goal is exceeded are similar to the timescales for which temperature exceeds the goal.[25]

20. Experts indicated that a temperature-only limit will not capture all changes in the climate system that follow from GHGs emissions and may thus lead to other changes being overlooked. This is because large-scale climate system responses, including those related to ocean acidification[26] and sea level rise,[27] may be affected by more than temperature, or show delayed responses to temperature.

Message 1

A long-term global goal defined by a temperature limit serves its purpose well

Parties to the Convention agreed on an upper limit for global warming of 2 °C, and science has provided a wealth of information to support the use of that goal. Despite the irreversibility of global warming, cutting carbon dioxide (CO_2) emissions now affects future warming within a few years. Removing CO_2 from the atmosphere results in cooling. Adding **other limits** to the long-term global goal, such as sea level rise or ocean acidification, **only reinforces the basic finding** emerging from the analysis of the temperature limit, namely **that we need to take urgent and strong action to reduce GHG emissions**. However, the limitations of working only with a temperature limit could be taken into account, for example, by aiming to limit global warming to **below 2 °C**.[a]

[a] See annex II, paragraph 47.

21. In terms of **reducing global GHG emissions** in order to limit global warming, the IPCC showed that the cumulative amount of total anthropogenic CO_2 the world can emit is limited. There is an approximately linear relationship between cumulative total anthropogenic CO_2 emissions and the global average temperature rise. Therefore, limiting global warming implies a maximum amount of cumulative CO_2 emissions. This means that **halting the global average temperature rise at any level will require net zero global CO_2 emissions** at some point in the future.[28] Furthermore, because of the cumulative budget constraint, higher global emissions in the near term would require lower global emissions in the long term, and, in case of overshooting, the use of CO_2 removal technologies.[29]

[24] See paragraph 56 below.

[25] If we overshoot emissions for 50 years we might stay above the target (concentration and temperature) for 50 years (see annex II, paras. 67 and 68).

[26] See annex IV, paragraph 249.

[27] Unlike global average warming, the rate of global mean sea level rise also depends on the pathway of CO_2 emissions, which means that reducing emissions earlier rather than later leads to a lower sea level rise (see annex II, paras. 26 and 38, and figure 16).

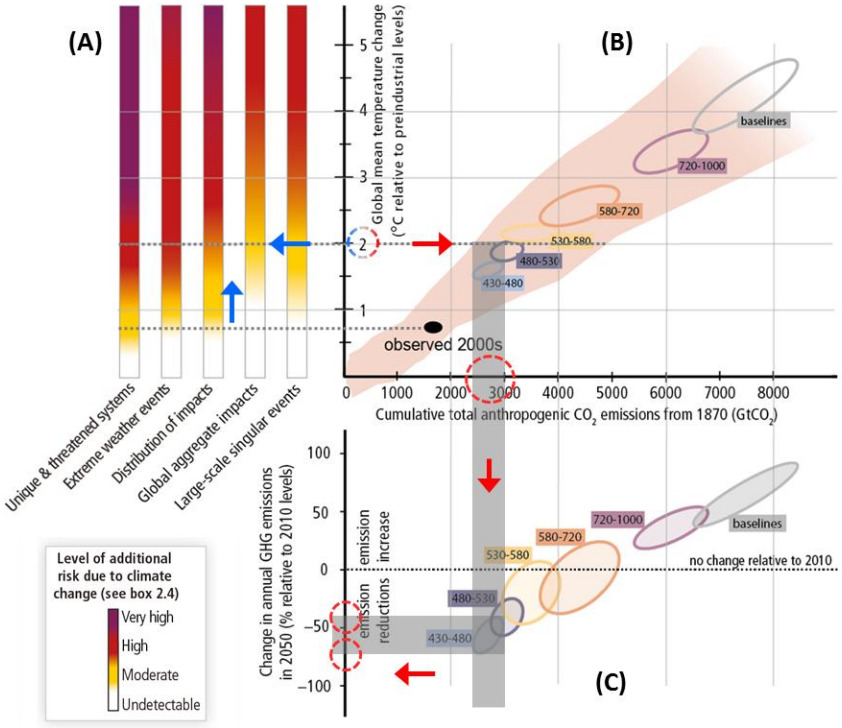
[28] See annex II, paragraphs 35, 59 and 60. For example, the upper amount is 1,000 Gt C for a probability greater than 66 per cent of staying under 2 °C. This amount is reduced to about 790 Gt C when accounting for non-CO_2 forcing as in scenario RCP2.6.

[29] See annex III, paragraphs 131 and 132, and figure 42.

22. Figure 4 illustrates that aggregated risks from climate change (panel A) depend on the level of global warming and cumulative CO_2 emissions (panel B), which in turn depend on global annual GHG emissions over the next decades (panel C). Limiting global warming to **below 2 °C in the long term implies** (follow red arrows) **a limit for cumulative CO_2 emissions**, which can be estimated from the corresponding category of least-cost mitigation pathway scenarios (panel B, 430–480 ellipse). This limit also implies, **in the near term, a constraint for changes in annual GHG emissions by 2050** relative to 2010 (panel C, 430–480 ellipse).[30] The figure also shows that, at 2 °C of warming, aggregated risks of climate change for unique and threatened systems from extreme weather events and from distribution of impacts will become high (panels A and B, upper dotted horizontal line). Additionally, such risks from global aggregated impacts and large-scale singular events will become moderate compared with their current levels (panels A and B, lower dotted horizontal line).

Figure 4

The relationship between global average temperature change, risks from climate change, cumulative anthropogenic carbon dioxide emissions and changes in global annual greenhouse gas emissions by 2050 relative to 2010 for 2 °C of warming above pre-industrial levels



Source: Adapted from the summary for policymakers in the Synthesis Report of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.10.

Note: Limiting aggregated risks from climate change (panel A) by a global average temperature limit of 2 °C (blue/red circle in panel B) implies, through the limited carbon budget (red circle at bottom of panel B), a reduction in annual GHG emissions of 40–70 per cent relative to 2010 emissions by 2050 (red circles in panel C).

Abbreviation: GHG = greenhouse gas.

23. In terms of **GHG emission pathways**, a scenario analysis shows that the 2 °C limit requires a large global emission reduction in the short to medium term, and near-zero or negative global emissions in the second half of the twenty-first century (40–70 per cent

[30] See annex IV, paragraphs 35–37 and 61–63; and figures 57, 58, 68 and 69.

reduction in GHGs globally from 2010 levels by 2050 and near- or below-zero global GHG emission levels in 2100 in order to likely limit global warming to below 2 °C).[31] According to UNEP, to stay within the 2 °C warming limit, global CO_2 emissions need to decrease to net zero between 2055 and 2070, and all GHGs emissions need to decrease to net zero between 2080 and 2100. The longer we wait to bend the curve of currently increasing global emissions of GHGs, the steeper we will have to bend it down later, even with negative emissions towards the end of the century.[32] Even a 3 °C limit requires a substantial reduction in global GHG emissions, a fundamental transformation of the energy system and global GHG emission levels towards zero by 2100.[33]

24. **Parties sought clarification** on, inter alia: uncertainties associated with the cumulative CO_2 budget, the corresponding global emission reductions for remaining under 2 °C of warming, and the implication for the policymaking process of a wide range of estimates being provided;[34] the importance of global emission pathways; current anthropogenic concentration of CO_2 eq and the number of years we can still emit at current rates while limiting warming below 2 °C or 1.5 °C; pathways for global non-CO_2 emissions; and the relationship between emissions and the capacity of land and ocean sinks.

25. Regarding uncertainties and the ranges of estimates provided, experts clarified that the findings of the Working Group III (WGIII) of the IPCC refer to cost-effective mitigation scenarios while explicitly considering societal uncertainties, such as delaying actions or unavailability of technologies, while the findings of Working Group I (WGI) include uncertainty in the geophysical response. Experts emphasized repeatedly that in the context of risk management, larger uncertainties will mean a lower carbon budget.[35]

26. With regard to global GHG emission pathways, experts underscored that they could lead to different rates of change in the climate system, resulting in different types and rates of impacts (see para. 27 below), and that therefore global emissions must peak and then decline in the near future for a range of scenarios and warming limits. **CO_2 removal technologies** are needed to compensate for past GHG emissions overshooting the target and, more importantly in the second half of the century, also for emissions that cannot be reduced to zero (e.g. non-CO_2 emissions from agriculture). Although reducing non-CO_2 emissions can be an important element of mitigation strategies, the temperature change is mainly determined by the cumulative budget of CO_2 emissions, and CO_2 emissions drive long-term warming.[36]

27. Noting that the atmospheric concentration of CO_2 eq in 2011 was about 430 ppm, experts stressed the difficulty of achieving a 430–480 ppm concentration in 2100 without a temporary concentration overshoot. They warned that simple calculations of the remaining number of years of emitting at current levels while limiting warming to below 2 °C or 1.5 °C based on the cumulative budget, without considering the possibility of achieving negative emissions, may make achievement of the temperature limit appear too challenging.[37] While noting the difficulty of quantifying changes in land and ocean sinks for high-emission scenarios, experts stressed that the direction is clear: the higher the emissions, the more the capacity of sinks will be weakened.

[31] See annex III, paragraph 131.
[32] See annex IV, paragraph 115, and figure 78.
[33] See annex III, paragraphs 112 and 132.
[34] Working Group I indicated a 14–96 per cent reduction below 1990 levels in 2050, while Working Group III indicated a 40–70 per cent reduction below 2010 levels in 2050.
[35] See annex II, paragraph 64, annex IV, paragraph 88, and figure 14. See also the pink plume and the ellipsis in figure 4.
[36] See annex III, paragraph 166, and annex IV, paragraph 84.
[37] See annex IV, paragraph 92.

Message 2

Imperatives of achieving the long-term global goal are explicitly articulated and at our disposal, and demonstrate the cumulative nature of the challenge and the need to act soon and decisively

Scenario analysis shows that limiting global warming to below 2 °C implies the following: a large reduction in global greenhouse gas emissions in the short to medium term, global carbon dioxide neutrality early in the second half of this century, and negative global greenhouse gas emissions towards the end of the twenty-first century.[a] The longer we wait to bend the currently increasing curve of global emissions downward, the steeper we will have to bend it, even with negative emissions. **Limiting global warming to below 2 °C necessitates a radical transition** (deep decarbonization now and going forward), **not merely a fine tuning of current trends**.

[a] See annex II, paragraph 23.

B. Theme 1 of the review – the adequacy of the long-term global goal in the light of the ultimate objective of the Convention

28. The adequacy of the long-term global goal can be assessed by examining the level of risk of climate impacts for any given level of global warming and determining whether these risks are unacceptably high and should therefore be decreased. To this end, the SED considered the adequacy of the goal in the following terms: current risks and observed impacts of climate change, future risks and impacts at 2° C warming, and future risks and impacts avoided in relation to a 'business as usual' scenario.[38] Furthermore, the SED also considered the feasibility of limiting global warming to below 2 °C within a global risk management framework that respects planetary boundaries.

1. Risk framing of climate impacts

29. The AR5 framed impacts of climate change in terms of risks (figure 5) and assessed hundreds of emerging and key risks at the global, regional and sectoral levels. Each risk was assessed for the present, the near term and for levels of warming of 2 °C and 4 °C above pre-industrial levels, including variants for reducing risks with adaptation at "current" and "high" levels (figure 6). Risk levels often increase with temperature and are sometimes linked to the rate of warming as well as to magnitudes of sea level rise and ocean acidification.

30. In figure 6, the benefits of mitigation are shown by the difference in the level of risk for 2 °C and 4 °C of warming (the grey area of each bar represents an assessed risk). Near-term (2030–2040) risks are similar for all RCP scenarios because in the near term warming does not vary significantly, with atmospheric GHG concentrations remaining at first similar. Therefore, adaptation provides the main opportunities to control risks for this period. However, mitigation investments made in the immediate future play an essential role in addressing climate change throughout this century and in the long term in general.[39]

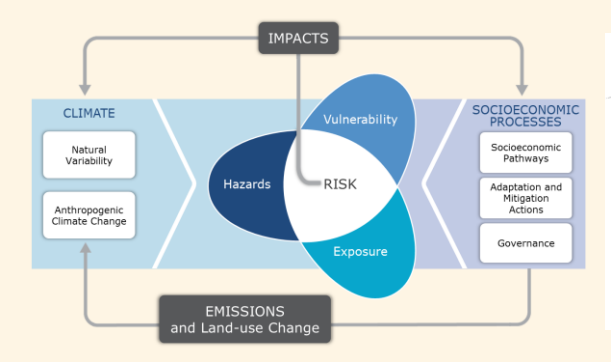
31. Sectoral risks at the global scale and some 80 regional risks were condensed into eight key risks, such as risks of death, injury or disrupted livelihoods. Key risks include severe ill health and disrupted livelihoods for large populations due to inland flooding in some regions, such as low-lying coastal zones, and systemic risks due to extreme weather

[38] With a focus on enabling ecosystems to adapt naturally to climate change, ensuring that food security is not threatened, and enabling economic development to proceed in a sustainable manner.

[39] See annex III, paragraph 18.

events leading to a disruption or breakdown of infrastructure networks and critical services. These key risks have been further aggregated and translated into five reasons for concern (RFC), which illustrate the implications of warming and of adaptation limits for people, economies and ecosystems across sectors and regions (figure 4, panel A).[40]

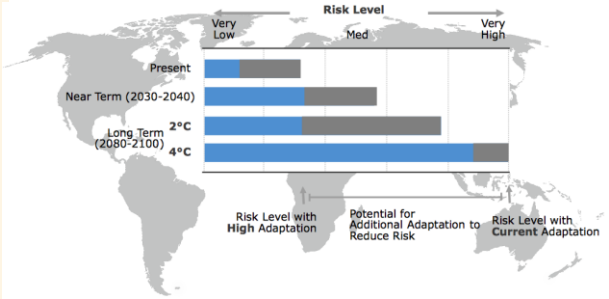
Figure 5
Illustration of the core concept of climate risks



Source: Summary for policymakers in the contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.1.

Note: To some extent climate risks can be managed, since they result from the interaction of climatic hazards, vulnerability and exposure.

Figure 6
Assessing climate risk by considering 102 global, regional and sectoral key risks



Source: Slide 13 of the presentation by Mr. Chris Field (Intergovernmental Panel on Climate Change) at the third session of the SED, available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/0_field_sedpart1.pdf>.

Note: Benefits of mitigation are shown by the risk reduction from the forth (4 °C) to the third (2 °C) risk bar. The benefits of adaptation are shown by the risk reduction represented by the grey parts of the risk bars (blue = 'high' adaptation levels, blue plus grey = 'current' adaptation levels). No particular risk is shown in this schematic figure; see figure 7 for examples of actual risks.

32. The risks assessed illustrate how complex and different regional vulnerabilities are (figure 7). Examples of such risks are: food insecurity and malnutrition (high and very high risks in Africa, Asia, and Central and South Asia in relation to a global temperature increase of 4 °C); floods (in all regions with most of the population affected in East, South-East and South Asia owing to an increase in exposure and vulnerability, including costal floods and inundation in low-lying coastal areas such as in Small islands, Asia, Australasia and North America); extreme heat and heatwaves (e.g. in Europe, Asia and Australia); ecosystems without adaptation potential (high and very high risks, already in the near term, in polar regions and oceans (e.g. corals), the latter also for a warming of 2 °C); drought, water shortages (in all regions, in particular if already dry now); and increased damage from wildfires (e.g. North America, Europe and others).[41]

33. **Parties sought clarification** on, inter alia: the qualification of risks, including why some risks have been deemed high and how local risks have been used to determine regional or global risks; the level of warming at which rapid change in risk level may take place; comparability of risks and how risks could be weighted; how 'high' adaptation is defined and if it includes forced relocation; and if adaptation was considered in determining the climate risks associated with the RFC.

34. Experts indicated that they used coordinated expert judgment based on a set of explicit criteria to qualify the level of risk and the possibility for adaptation. Noting that aggregation into key risks may mask local high risks, they clarified that information on

[40] See annex III, paragraphs 30–33.
[41] See annex III, paragraph 40.

such risks is available in the underlying report[42] and underscored the importance of the regional risk assessments.[43] They explained that: the AR5 identified hot spots[44] that could be the focus of specific policies; the rate of change that is tolerable is preferable to a guardrail threshold, for example owing to non-linear responses of organisms to climate stressors; and considering the ways in which risks interact is key.[45] The risk concept is robust and enables better comparability, but limitations still exists, for example because of the different causes of risks or of methodologies used in studies. Autonomous adaptation, as well as limits to adaptation, have been taken into account for the RFC for unique and threatened systems, distribution of impacts and large-scale singular events, independently of the development pathway.[46]

35. Adaptation can be restricted by a range of factors, such as those related to geography, high-emission pathways or socioeconomic constraints in adaptive capacity.[47] On the concept of 'high' adaptation, participants in the discussions pointed out that forced relocation is hardly an option for small island developing States, as it implies fundamental changes in livelihoods and cultural values. Experts clarified that they considered the most probable development pathways for each region and that the definition of a highly adaptive state was left to the writing team to assess taking into account the cultural environment and other limits that may persist, in particular economic ones, as long as adaptation is not seen as a cost-effective investment. Furthermore, constraints to 'high' adaptation are context-sensitive and reflect the fact that adaptation is in general difficult to assess, particularly for long-term time frames, beyond mid-century.[48]

Message 3

Assessing the adequacy of the long-term global goal implies risk assessments and value judgments not only at the global level, but also at the regional and local levels

The global climate determines regionally experienced risks. While global assessments of climate risks inform global policy choices and global risk management, they should be complemented by regional and local perspectives. A key element of these perspectives is the value judgment of when the scale (e.g. frequency and severity) of climate impacts results in a transition from 'acceptable' to 'unacceptable'.[a] This leads to a greater appreciation of the role played by all decision makers, including subnational authorities and cities.

[a] See annex III, paragraphs 20, 23, 54 and 97.

2. Current risks and observed impacts of climate change

36. According to the AR5, the observed impacts of climate change **at 0.85 °C of warming** are consequential and wide-ranging, spanning all regions and sectors.[49] Impacts have been observed on: food production, including constraints on the increase in wheat and maize yields, and negative impacts on marine fisheries; sea level rise and its associated impacts on low-lying coastal zones including small islands; glaciers and ice sheets, including consistent mass loss, and Arctic systems; ecosystems, including increased tree mortality, resulting in some cases in forest dieback, as well as negative impacts on Arctic,

[42] See annex III, paragraph 64.
[43] See annex III, paragraph 57.
[44] Areas where risk is very high or where risk levels could change significantly.
[45] See annex III, paragraph 65.
[46] See annex IV, paragraph 96.
[47] See annex III, paragraph 39.
[48] See annex III, paragraph 58.
[49] This refers to impacts due to climate change irrespective of its causes.

freshwater and terrestrial species and warm water coral reefs; and sustainable economic development, including impacts on livelihoods and increased economic losses from extreme weather.[50] Furthermore, key current climate risks are already high in some regions (figure 7).

37. The regional chapters of the contribution of IPCC Working Group II (WGII) to the AR5 and presentations of observed impacts in the Caribbean, the Pacific and the Arctic regions, as well as on agriculture, illustrated how these impacts vary across regions and populations.[51] Some regions have a substantial economic dependence on climate-sensitive sectors, such as ecosystem services and tourism, with limited opportunities for economic diversification. Adaptation potential is limited for many of the observed impacts of climate change, and implementation of adaptation options, if available, comes at very high cost in relation to countries' national budgets.

38. Climate-related hazards exacerbate other stressors, such as socioeconomic and environmental stressors, and have a negative impact on people and livelihoods, with the emergence of critical thresholds when all stressors converge. As warming continues, climatic stressors will play an increasingly important role, largely determined by the emission pathway chosen.[52] While more and more impacts are attributable to climate change, the attribution is sometimes difficult owing to non-climatic stressors and the influence of other convoluting factors further down the chain of impacts.[53]

39. Deliberations revealed that the current level of warming is causing certain impacts that are beyond the current adaptive capacity of many people.[54] **Parties sought clarification** regarding: the discrepancy between the qualification of risk to unique and threatened systems as 'moderate' at current warming (owing to unevenly distributed impacts) and the fact that they are high in many areas; and the safe levels of impacts at which the objective of the Convention can still be achieved.

40. Experts explained that the aggregation of risks is masking regional differences, that the level of risk is related to the number of causal links[55] that the IPCC was able to assess in developing the RFC, and there are limits to characterizing every possible combination of risks that have potential impacts. On the qualification of 'safe' or 'dangerous' levels of impacts, experts noted that this depends on the scale, frequency and severity of the impact, and implies a value judgment. From the perspective of a species, an individual or a village that is already facing severe impacts, the current level of warming can already be unsafe.

[50] See annex III, paragraphs 17 and 35–37; and figures 21 and 24.
[51] See annex IV, paragraphs 258–265 and 271–291.
[52] See annex III, paragraph 29.
[53] Non-climatic factors are currently the dominant drivers of observed changes in terrestrial ecosystems, with the exception of highly temperature-sensitive systems, such as the polar regions, high mountains and the tropics (annex III, paras. 34, 35 and 37; annex IV, para. 89; and figures 21 and 24).
[54] See annex III, paragraphs 54 and 97.
[55] See annex III, paragraph 79.

Message 4

Climate change impacts are hitting home

Significant climate impacts are already occurring at the current level of global warming and additional magnitudes of warming will only increase the risk of severe, pervasive and irreversible impacts. Therefore, **the 'guardrail' concept, which implies a warming limit that guarantees full protection from dangerous anthropogenic interference, no longer works.**[a] This calls for a consideration of societally[b] or otherwise acceptable risks of climate impacts.

[a] See annex III, paragraphs 54 and 97.
[b] See annex III, paragraph 54, and annex IV, paragraph 163.

3. Future risks and impacts of climate change for a 2° C rise in global average temperature and avoided impacts of climate change in relation to a 'business as usual' scenario

41. On future risks and impacts of climate change, experts warned that the increasing magnitude of warming will only increase severe, pervasive and irreversible impacts.[56] They also indicated that for any level of global warming, regional differences in impacts are projected to become more pronounced.

42. In **a world 2 °C warmer** than in pre-industrial times, the rate of climate change would become too rapid for some species to move sufficiently fast and migrate to their preferred temperature zones;[57] long-term sea level rise may exceed 1 m; Arctic summer sea ice will be further significantly reduced; some unique systems would be at high risk; the risks of combined ocean warming and acidification would become high, and, for some phenomena such as mass coral bleaching, very high; and crop production would be at high risk with some potential for adaptation.[58] Many more moderate and high risks would emerge: indigenous people would be at risk of loss of land and cultural and natural heritage, and cultural practices embedded in livelihoods would be disrupted. The IPCC expert named as damage the residual risk that remains with a 2 °C temperature rise accompanied by 'high' adaptation.[59] Furthermore:[60]

(a) Unique and threatened systems would be at high risk, in particular systems with limited or barely any adaptive capacity (e.g. Arctic sea ice and coral reefs);[61]

(b) Extreme weather events would pose a high risk for human health, urban housing and infrastructure in megacities, also in relation to the urban heat island effect, air pollution and differential vulnerabilities; displacement and permanent migration; livelihood struggles and conflict in resource-dependent livelihoods, such as agriculture and pastoralism; and high impacts on livelihood (trapped populations are more vulnerable to environmental change because of their inability to move);[62]

[56] See annex I, paragraph 19, and annex III, paragraphs 18 and 33.
[57] See annex III, paragraph 19; and annex IV, paragraph 43.
[58] See annex IV, paragraph 43
[59] See annex III, paragraph 26.
[60] See also the AR5 Synthesis Report, box 2.4, on reasons for concern regarding climate change.
[61] See annex IV, paragraphs 43, 78 and 244; see also the AR5 Synthesis Report, box 2.4.
[62] See annex III, paragraphs 73 and 105, and annex IV, paragraph 49.

(c) The risks will be increasingly unevenly distributed, and are generally greater for disadvantaged people and communities in countries at all levels of development; populations that experience shifts from transient to chronic poverty and related social marginalization and food insecurity; and the elderly, children, the socially marginalized, and outdoor workers, who are disproportionally at risk from heat stress;[63]

(d) Global aggregate impacts show a moderate economic impact, but these aggregates may mask impacts across sectors and regions (evaluations are incomplete, in part because they do not take into account large-scale singular events affecting several sectors at once or other effects from disrupted interdependencies);[64]

(e) The risk of large-scale singular events, such as the disintegration of ice sheets in Greenland and Antarctica, would be moderate.[65]

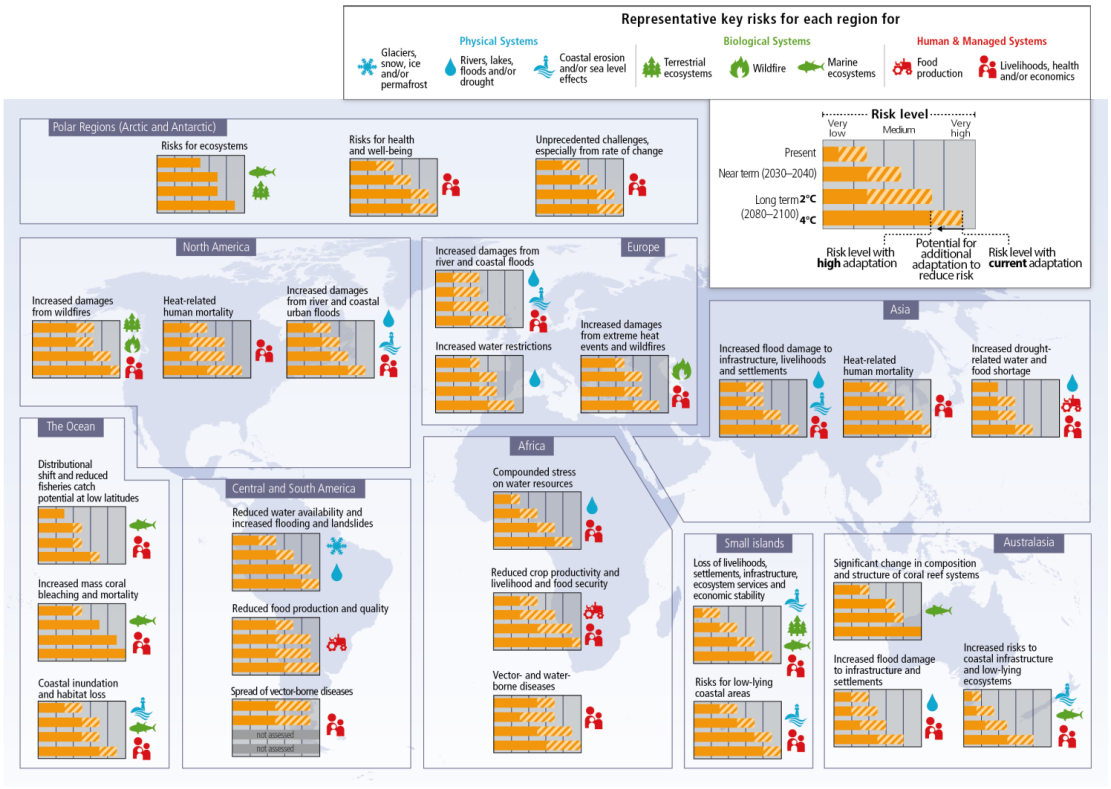
43. In a **world 4 °C warmer, many global risks are high and very high**.[66] Most projected ecosystem impacts would occur at high risk levels. Climate change velocity would be much too high for terrestrial and freshwater species to move sufficiently fast. Biodiversity losses would take place, including substantial species extinction and disruption of ecosystem services. The risks of combined ocean warming and acidification would become very high. The catch potential of fisheries would be greatly reduced, and crop production would be at very high risk with no potential for adaptation. The long-term sea level rise would far exceed 1 m, and Arctic summer sea ice would be lost. Some unique systems would be threatened, and the risks from extreme weather events would become very high, or medium to high with adaptation. These risks would put people who are socially, economically, culturally, politically, institutionally or otherwise marginalized at most risk.

44. During one discussion, a World Bank expert underlined the non-linearity of projected risks and impacts as we move from 2 to 4 °C of warming, in particular in relation to water availability, heat extremes or the bleaching of coral reefs, with close to double impacts in a world 4 °C warmer compared with one 2 °C warmer than in pre-industrial times, implying very different adaptation needs.[67] A WHO expert stated that in a world 4 °C warmer, the health risks are very high in comparison with current levels.[68]

[63] See annex III, paragraphs 40 and 43, and annex IV, paragraphs 47 and 49.
[64] See annex III, paragraph 65, 74 and 103, and annex IV, paragraph 49.
[65] See annex II, paragraph 39, annex III, paragraph 153, and figure 4; see also the AR5 Synthesis Report, box 2.4.
[66] See annex III, paragraphs 40, 42, 43, 63, and 69, annex IV, paragraphs 30, 33, 49, 244, 255, 275, 286 and 311, and figures 59 and 103; see also the AR5 Synthesis Report, box 2.4.
[67] See annex IV, paragraph 120, which indicates that water availability is projected to be reduced by 20 per cent at 2 °C of warming and by 50 per cent at 4 °C of warming.
[68] See annex IV, paragraph 143.

Figure 7

Representative key risks for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation



Source: Summary for policymakers in the Synthesis Report of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.8.

Note: The figure shows representative key regional risks (see also figures 5, 6, and para. 32 of the document).

45. Significant opportunities for adaptation exist in a world 2 °C warmer, although under all of the assessed scenarios some residual risk from adverse impacts remains. There are limited prospects for risk reduction through adaptation in a world 4 °C warmer, and impacts would significantly increase in all regions.[69] With that amount of warming, limits to adaptation would be reached in relation to aspects such as urban water supply systems. heat-sensitive people, agricultural productivity and food security, means of implementation, and the preservation of cultural identity.[70] Moreover, the adaptation potential in case of conflict over land acquisition and displacement will decline significantly, risks of food insecurity (Africa and Asia) and malnutrition (Africa and Central and South Asia) will be high and very high,[71] and flooding risks will become more widespread in Asia and in Central, South and North America.[72]

46. Parties sought clarification on risk related to urban–rural interaction and on impacts of climate change on poverty reduction. Experts clarified that the urbanization process taking place in developing countries will exacerbate risks such as high mortality, injuries or loss of infrastructure mainly owing to the high population density resulting from

[69] See annex III, paragraphs 39 and 43.
[70] See annex IV, paragraph 50.
[71] See annex III, paragraph 40.
[72] See annex III, paragraph 42.

urbanization and gaps in infrastructure.[73] On the impacts of climate change on poverty reduction, they indicated that climate change in a world 2 °C warmer is already expected to slow down economic growth and hinder poverty reduction efforts, in particular in vulnerable countries.[74]

Message 5

The 2 °C limit should be seen as a defence line

Limiting global warming to below 2 °C would significantly reduce the projected high and very high risks of climate impacts corresponding to 4 °C of warming, which is where we are headed under a 'business as usual' scenario. It would also allow a significantly greater potential for adaptation to reduce risks. However, many systems and people with limited adaptive capacity,[a] notably the poor or otherwise disadvantaged, will still be at very high risk, and some risks, such as those from extreme weather events, will also remain high. Adaptation could reduce some risks (e.g. risks to food production could be reduced to 'medium') but the risks to crop yields and water availability are unevenly distributed. Moreover, the risks of global aggregated impacts and large-scale singular events will become moderate. **The 'guardrail' concept, in which up to 2 °C of warming is considered safe, is inadequate and would therefore be better seen as an upper limit, a defence line that needs to be stringently defended, while less warming would be preferable**.

[a] See annex III, paragraph 39, which cites the example of systems such as the cryosphere, the Arctic, high mountains and coral reefs.

4. Feasibility of limiting global warming to below 2 °C in the context of a global risk management framework within planetary boundaries

47. The risks of climate change can be significantly reduced if warming is limited to below 2 °C, but that limit requires deep cuts in global GHG emissions. Such cuts imply the scaling-up of low-carbon technologies,[75] which poses substantial technological, economic and institutional challenges, in particular in the energy sector and potentially in land use. Mitigation action has co-benefits but also risks.[76]

48. The AR5 indicated that immediate mitigation, before 2030, would result in multiple cost-effective mitigation pathways for limiting warming to below 2 °C above pre-industrial levels (figure 8, left-hand side panel, dark green trajectories). This would be characterized by an annual rate of CO_2 emission reduction after 2030 of about 3 per cent (median value, middle panel) and would require a roughly a 90 per cent scaling-up of low-carbon energy technologies by 2050 compared with 2010 (right-hand side panel). Delaying mitigation (left-hand side panel, light green trajectories, "Cancun pledges") requires a more ambitious profile after 2030, characterized by an annual rate of CO_2 emission reduction of about 6 per cent (median value), which implies a dramatic tripling of low-carbon energy technologies, with related significant risks.

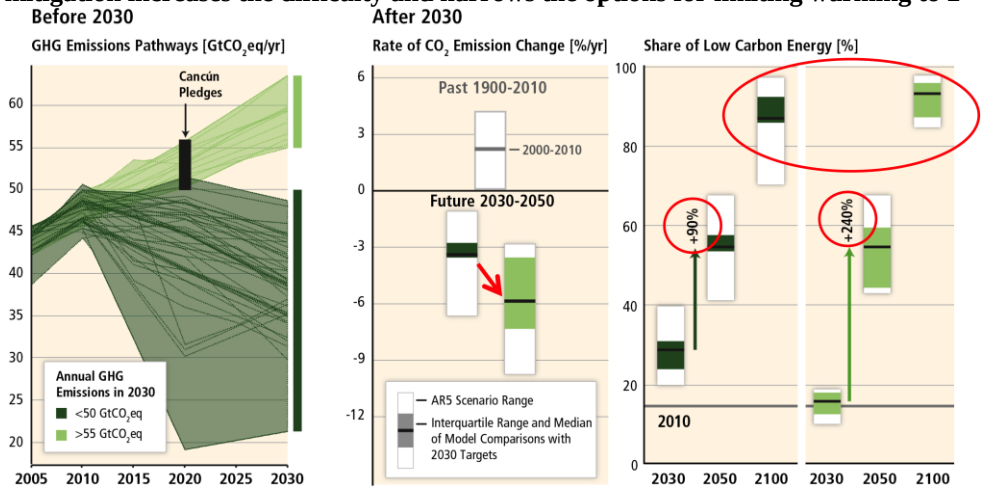
49. Available **estimates of mitigation costs** vary widely, but do not significantly affect global gross domestic product (GDP) growth. Uncertainties surrounding the global mitigation costs are due to varying model assumptions, which are partially due to the differences in estimates of the rates of low-carbon technology uptake. While global costs rise with the level of ambition of mitigation action, this action would marginally delay, but

[73] See annex III, paragraph 103.
[74] See annex IV, paragraph 81.
[75] Approximately by 300 per cent above current levels by 2050.
[76] See annex IV, paragraph 61.

not sacrifice, economic growth, which indicates that economic and emission growth can be decoupled.[77]

Figure 8

Delaying mitigation increases the difficulty and narrows the options for limiting warming to 2 °C



Source: Slide 13 of the presentation by Mr. Edenhofer (Intergovernmental Panel on Climate Change) at the 1st meeting of the fourth session of the Structured Expert Dialogue, available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141202_sed_edenhofer_lima_final4.pdf>.

Note: Emission pathways (left), annual emission reduction rates (middle) and share of low-carbon technologies (right) for a "soon and decisive mitigation action" (dark green) versus challenges and risks of delayed and more costly action (light green) (see para. 48 for details).

Abbreviations: AR5 = Intergovernmental Panel on Climate Change Fifth Assessment Report, CO_2 eq = carbon dioxide equivalent, GHG = greenhouse gas.

50. **The availability of technologies** seriously affects mitigation costs. Moreover, technological limitations or delaying the availability of technologies will increase the costs and reduce the feasibility of low-carbon scenarios. Without carbon dioxide capture and storage (CCS) and with limited availability of bioenergy, the mitigation costs would increase markedly in the medium term.[78]

51. The IEA presented some cost-effective short-term action that could stop the growth in emissions by 2020 at no net economic cost, reducing emissions by 3.1 Gt CO_2 eq and making 80 per cent of the savings required for a 2 °C pathway.[79] Mitigation scenarios indicate the need to **fully decarbonize energy systems**, but there is flexibility in that process, and carbon pricing allows all sectors of the economy to identify 'low-hanging fruit' in terms of mitigation.[80] The IPCC has stressed that a consistent carbon pricing, covering all sectors of the economy, is a defining feature of the 2 °C scenarios.[81]

52. Mitigation action comes with **co-benefits,** in particular for human health, biodiversity conservation and other societal goals, that are however challenging to define and quantify. The IEA emphasized that in many cases these non-climate drivers are the real

[77] See annex III, paragraph 115. According to the IEA, global emissions of CO_2 from the energy sector stalled in 2014, marking the first time in 40 years that a reduction in emissions was not tied to an economic downturn, <http://www.iea.org/newsroomandevents/news/2015/march/global-energy-related-emissions-of-carbon-dioxide-stalled-in-2014.html>.

[78] See annex III, paragraph 115.

[79] See annex IV, paragraph 132.

[80] See annex III, paragraphs 116 and 183, and annex IV, paragraph 133.

[81] See annex III, paragraphs 183, 184 and 187.

reasons that governments take action and should therefore be harnessed.[82] The IPCC found that there are many opportunities to link mitigation, adaptation and the pursuit of other societal objectives through integrated responses.[83] However, some experts pointed out that mitigation action has not only co-benefits, but also risks,[84] although these risks are not of the same severe, widespread and irreversible nature as climate change risks.[85]

53. Noting that the optimal balance of mitigation, adaptation and residual impacts cannot be determined with current knowledge,[86] experts stressed that mitigation and adaptation are complementary approaches to reducing climate change impacts over different timescales. Experts also noted that the risks from mitigation and adaptation can be identified and managed.

54. **Parties sought clarification** on the window of opportunity for staying under 2 °C of warming and the risks created by overshooting, the practicality of achieving negative emissions, the marginal costs of mitigation for 40–70 per cent emission reduction from 2010 levels by 2050, the Cancun pledges, the impact of mitigation on economic growth, and production- versus consumption-based accounting for emissions.

55. Experts clarified that the **window of opportunity** is determined by how quickly low-carbon technologies can be scaled up and by the associated risks, rather than by atmospheric physics, which is only the boundary condition. Mitigation action over the next decade will determine the amount and cost of mitigation action required after 2030. Risk related to scaling up low-carbon technologies increases when mitigation is delayed, and overshooting is a typical feature of low-stabilization scenarios, which all have risks.

56. The **practicability of negative emissions** depends on costs, trade-offs and the feasibility of various scenarios. The IPCC presented options for generating large amounts of energy from BECCS and the associated risks for biodiversity and food security and prices, stressing that policymakers need to consider the trade-offs.[87] If CCS and therefore BECCS technologies are not available, for example because of the associated storage risks, the land use and forestry sector must contribute significantly to the mitigation effort. To reduce the associated risks, BECCS should be accompanied by an integrative institutional framework that takes into account the competition for land, notably a carbon-pricing mechanism that covers all sectors, including land use.[88]

57. On **marginal mitigation costs**, experts underscored that the decision on reducing global GHG emissions by 40–70 per cent from 2010 levels by 2050 is not only a matter of cost, because mitigation action by 2050 will also influence the amount of negative emissions needed in the second half of the century.[89] Experts also stated that the **Cancun pledges are more consistent with a 3 °C** than a 2 °C temperature increase by 2100.[90] They also underscored that the impact of the Cancun pledges could differ substantially depending on their interpretation.[91]

[82] See annex III, paragraph 148, and annex IV, paragraph 136.
[83] See annex III, paragraph 116, and annex IV, paragraphs 75, 119, 147, 155, 171, 177, 180, 208, 243 and 298.
[84] See annex III, paragraphs 83, 84, 98 and 177, and annex IV, paragraphs 61, 75 and 243.
[85] See annex IV, paragraph 61.
[86] See annex III, paragraph 81, and annex IV, paragraph 58.
[87] See annex IV, paragraphs 75 and 243, and figure 90.
[88] See annex III, paragraphs 120, 157; and annex IV, paragraph 93.
[89] See annex III, paragraph 158.
[90] See annex III, paragraphs 113, 133, 145 and 191.
[91] See annex III, paragraph 160; and figure 6.

58. On **impact of mitigation on economic growth**, experts clarified that although climate mitigation can be seen as an opportunity cost (as it will reduce future consumption) it will also provide opportunities for new investments.[92] They noted that in an ideal world, the method used to account for emissions (production- versus consumption-based) would not change the results.[93]

Message 6

Limiting global warming to below 2 °C is still feasible and will bring about many co-benefits, but poses substantial technological, economic and institutional challenges

The costs are manageable, even without taking into account the co-benefits of mitigation, and various policy options could be deployed to manage the risks of the necessary mitigation action.

The feasibility of the long-term global goal could be assessed in an emerging, iterative, global risk management framework that has multiple feedbacks from different sources and takes into account planetary boundaries. To this end, periodic reviews would provide an opportunity to assess and reassess the overall progress towards reducing risks of climate impacts and progress of mitigation and adaptation action, thereby contributing to a science-based risk management of the pathways to a low-carbon and climate-resilient future.

C. Theme 2 of the review – overall progress made towards achieving the long-term global goal, including a consideration of the implementation of the commitments under the Convention

59. The SED considered current and possible future overall progress towards the long-term global goal. To this end it addressed issues related to measuring the overall progress made towards the long-term global goal, including its effect on the global average temperature. In this context, the SED also looked into the latest insights and updates from the IPCC and science in general, processes under the Convention, and other organizations, including the World Bank, IEA, WMO and UNEP, as well as progress made on finance, capacity-building and technology.

1. Measuring progress

60. The IPCC continued to use the global warming potential as the metric for comparing and aggregating global anthropogenic GHG emissions for various gases. Trends in stocks and flows of global GHG emissions were estimated with associated uncertainties. In terms of global GHG pathways, the IPCC indicated where science tells us we should be in 2050 to limit global warming below 2 °C (see paras. 21–23 above). The IPCC estimated current global warming and projected temperature changes for all RCP scenarios, as well as for all categories of most cost-effective mitigation scenarios (see paras. 15–18 above) and the associated probabilities of limiting global warming below 2 °C.

61. In terms of adaptation, the IPCC used qualitative metrics to describe observed climate impacts[94] and future risks of climate impacts.[95] For future risks, progress could be

[92] See annex III, paragraph 123.
[93] See annex III, paragraph 192.
[94] Ranges of confidence in attribution of impacts to climate change and type of contribution of climate change to impacts (minor or major contribution).
[95] See paragraphs 29–35 above.

measured by their reduction through adaptation and mitigation. The RFC have been used to ascribe the increase in globally aggregated risks of climate impacts to global warming. Possible progress in avoiding risks at the global scale could also be measured in terms of the difference between the levels of risk for each of the five RFC at current and future levels of warming.

62. UNEP presented an assessment of overall progress on mitigation and adaptation through the *Emissions Gap Report*[96] and the *Adaptation Gap Report*,[97] respectively. UNEP explained that the *Emissions Gap Report* assesses emission trends, where these trends seem to be taking us, where the full implementation of the Cancun pledges would take us, and where we need to be to stay below the 2 °C warming limit with some given probability.[98] Estimating the global adaptation gap is far more challenging than calculating the global emissions gap because of the lack of a globally agreed goal or metrics for adaptation, and because adaptation is a response to specific risks of climate impacts that are local in nature and vary over time.[99]

63. **Parties sought clarification** on the appropriate metrics for comparing all the consequences of the different global emission pathways for support of the 2013–2015 review, including the possibility of assessing step-wise progress towards the long-term global goal in terms of partial limits for temperature rise for pre-defined periods of time (e.g. a series of decades) throughout this century.

64. On assessing stepwise progress towards the long-term global goal by using partial limits for temperature rise, the IPCC explained that such an approach would be difficult owing to the high variability of temperatures, which is also responsible for the difficulty of predicting decadal temperatures. Some periods experience less warming, and these short-term trends could lead to incorrect conclusions, which would then be very challenging to correct. Instead, the IPCC suggested that the goal be revised based on past and future committed emissions, which are well documented and can be clearly translated into long-term warming trends. The IPCC also indicated that the relative uncertainty ranges are wider when using the global temperature potential compared to the global warming potential currently in use for comparing CO_2 with other greenhouse gases.[100] On the appropriate metrics for comparing all the consequences of different emission pathways in order to support the review of the adequacy of the long-term global goal, the IPCC indicated that several other metrics exist and that no single metric can accurately compare all the consequences of different emission pathways. The selection of the metric depends also on the policy goals and their time horizon.[101]

65. On progress made in determining metrics for adaptation, the IPCC explained that there is no single metric for assessing adaptation effectiveness and needs. This assessment is based on the recognition that the best adaptation options address multiple dimensions of vulnerability and contribute to other mitigation and sustainable development goals. It is therefore very difficult to apply an additionality criterion while evaluating the effects of

[96] The 2014 report is available at <http://www.unep.org/publications/ebooks/emissionsgapreport2014/>.
[97] The 2014 report is available at <http://www.unep.org/climatechange/adaptation/gapreport2014/>.
[98] See annex IV, paragraph 110.
[99] See annex IV, paragraph 102.
[100] See annex II, paragraph 65, annex III, paragraph 126, and annex IV, paragraph 86. See also footnote 10 and paragraph 23 above.
[101] See annex II, paragraph 27.

adaptation investments,[102] and no standardized methodology exists to quantify the benefits of adaptation.[103]

Message 7

We know how to measure progress on mitigation but challenges still exist in measuring progress on adaptation

A generally accepted metric exists for aggregating and measuring overall progress on mitigation, but no single metric exists to quantify and aggregate the overall progress on adaptation. Similarly, a widely accepted metric to measure overall progress on reducing risks of climate impacts by adaptation would be required in the context of a global risk management framework.

2. Progress in terms of mitigation and adaptation

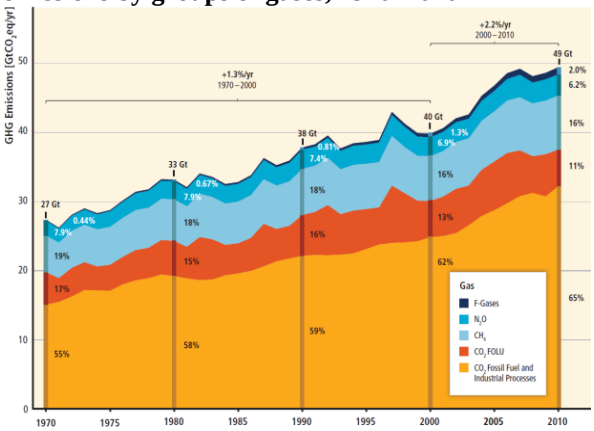
66. On the aggregated effects of steps taken by Parties, the SED addressed the following: trends in stocks and flows of GHG emissions; the effectiveness of past mitigation policies; information from Parties on their emission reduction efforts; and efforts made by Parties in identifying and addressing their adaptation needs.

67. Regarding **past and current global GHG emissions**, WGIII found that growth in global GHG emissions has accelerated despite mitigation efforts and the global economic crisis, and that emission growth between 2000 and 2010 was greater than in any of the previous three decades (figure 9).[104] In addition, about half of the cumulative anthropogenic CO_2 emissions between 1750 and 2010 occurred in the last 40 years.[105] The IPCC and WMO also underscored that this happened while roughly half of those emissions were absorbed by the oceans and the terrestrial biosphere.[106]

68. In terms of **progress in 2030**, the IPCC explained that the risks associated with negative emission technologies are significantly lower if annual global GHG emissions in 2030 are below 50 Gt CO_2 eq[107] than if they are in the range of 50–55 Gt CO_2 eq. These risks are very high for annual emissions over 55 Gt CO_2 eq in 2030 (figure 8). UNEP explained that the current global emissions gap is close to what was assessed in 2013, and that the gap has been almost constant for the past five years.[108] Based on several variants of current pledges, UNEP estimated that the emissions gap will be 7–10 Gt CO_2 eq in 2025, and significantly larger in 2030, at 14–17 Gt CO_2 eq (figure 10).[109]

[102] See annex III, paragraph 62.
[103] See annex III, paragraph 92.
[104] See annex III, paragraph 110.
[105] For information on GHG emissions from WGI, see annex II, paragraphs 54 and 55.
[106] See annex II, paragraph 55, and annex IV, paragraph 329.
[107] Note that global GHG emissions in 2010 were at this level and that, since then, emissions have increased further.
[108] See annex IV, paragraph 110.
[109] See annex IV, paragraph 112.

Figure 9
Total annual anthropogenic greenhouse gas emissions by groups of gases, 1970–2010

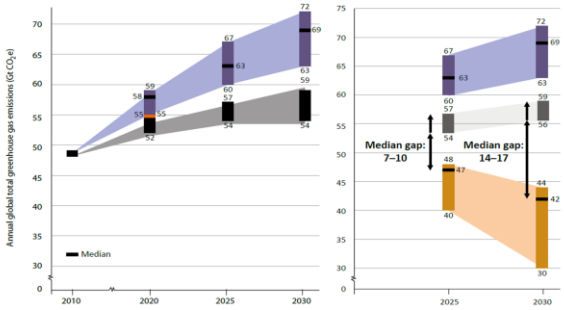


Source: Summary for policymakers in the contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.1.

Note: The figure illustrates that emission growth has accelerated in the last decade.

Abbreviations: CO_2 eq = carbon dioxide equivalent, F-gases = fluorinated gases, FOLU = forestry and other land use, GHG = greenhouse gas.

Figure 10
The emissions gap in 2025 and 2030



Source: Slide 4 of the presentation by Mr. John Christensen (United Nations Environment Programme), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_christensen.pdf>.

Note: The figure shows, based on Cancun pledges, the UNEP estimates that the emissions gap will be 7–10 Gt CO_2 eq in 2025, and significantly larger in 2030, at 14–17 Gt CO_2 eq.

Abbreviation: CO_2 eq = CO_2 equivalent.

69. In response to requests for clarification by Parties **on the reaction of sinks**, WMO indicated that there is uncertainty plus risks that sinks may change over time owing to the great inter-annual variability of the sinks, as well as the uncertainty about their future and the risk that this entails.[110]

70. On the **effectiveness of past policies**, the IPCC and UNEP emphasized that the current Cancun pledges are more consistent with pathways limiting global warming to 3 °C than 2 °C by the end of the century.[111] The IPCC also reported that from 2007 to 2012, the share of global emissions produced by countries with national climate policies rose from 45 to 67 per cent, and that these policies have not yet sufficiently influenced the emissions trend towards a reversal.[112] Emissions trading systems introduced to date suffer from caps that are too lenient and have thus experienced price decreases.[113] The World Bank reported on progress on eliminating fossil fuel subsidies and on carbon pricing, stressing the large co-benefits to development and well-being of the latter.[114]

71. **Parties sought clarification** on the effectiveness of emissions trading systems and carbon taxes, the removal of fossil fuel subsidies, the cost-effectiveness of commoditizing carbon in developing countries, and the price of carbon.

72. The IPCC indicated that there is agreement regarding the good performance of carbon taxes over the past 20 years, and that experiences with emissions trading over the past 10 years have been mixed.[115] The IPCC underlined that while a large number of clean development mechanism (CDM) projects have been generated, experts debate whether

[110] See annex IV, paragraph 329; see also annex II, paragraphs 56, 61 and 73.
[111] See paragraph 57 above, annex III, paragraphs 113 and 145, and annex IV, paragraph 110.
[112] See annex III, paragraph 144.
[113] See annex III, paragraph 148.
[114] See annex IV paragraph 119.
[115] See annex III, paragraph 161.

market-based mechanisms always fulfil the environmental integrity target.[116] Discussions, however, pointed to mitigation achieved and the finance mobilized through CDM projects. The IPCC also indicated that the assessment of policies shows the key role played by a consistent carbon price over a long period for the effectiveness of projects.[117]

73. Similarly to the World Bank (see para. 70), the IEA reported successful examples of eliminating fossil fuel subsidies. The World Bank added that in countries with weak institutions and low incomes, carbon taxes are much simpler than market-based instruments. Both carbon taxes and market-based instruments aim to raise revenue, which can be used to alleviate the shock of fossil fuel subsidy reforms.[118]

74. On **national information**, as indicated in a note on national information prepared by the secretariat,[119] challenges remain in bringing together the best available information from science and up-to-date reports from Parties and other processes under the Convention: a number of reports from the measurement, reporting and verification process were not available in time to be considered in the 2013–2015 review.[120]

75. **On progress on adaptation,** the Adaptation Committee reported on enhanced adaptation action in the context of the 2 °C limit to global warming, describing the three workstreams of its 2013–2015 workplan: technical support and guidance to Parties on adaptation action; technical support and guidance to Parties on means of implementation; and awareness-raising, outreach and sharing of information. The Adaptation Committee also described progress and lessons learned in the formulation and implementation of national adaptation plans (NAPs), noting that many programmes and activities that countries have been and are supporting already contribute to the objectives of the NAP process. The Adaptation Committee also stressed the need for appropriate monitoring and evaluation frameworks for adaptation that are tailored to country needs and circumstances.[121]

76. UNEP defined adaptation gaps, including the difference between what can be achieved with enhanced adaptation action and what society deems as the goal in terms of adaptation. This societal goal is not zero because society is ready to tolerate some amount of climate change impacts, which are determined by local cost-benefit analyses, and because some impacts are beyond our technical or physical ability to adapt.[122]

77. **Parties sought clarification** on: the fact that the Adaptation Committee has no specific focus on the long-term global goal; whether the recommendation to mainstream adaptation in development planning is appropriate for the least developed countries (LDCs); the importance of coordination among the three Rio Conventions in relation to NAPs; the term "societally desirable adaptation"; and how to address the adaptation gap.

78. The Adaptation Committee stated that despite the absence of a specific reference to the long-term global goal in its workplan, it would be difficult to argue that NAPs are not contributing to the achievement of the long-term global goal.[123] Experts indicated that whether countries decide to mainstream adaptation or carry out stand-alone projects depends on the types of hazards and exposure they face. In the case of LDCs, the consideration of reducing vulnerability comes as a complement to the second objective of

[116] See annex III, paragraph 161.
[117] See annex III, paragraph 189.
[118] See annex IV, paragraphs 172 and 181.
[119] FCCC/SB/2014/INF.3.
[120] See annex IV, paragraph 22.
[121] See annex IV, paragraphs 195–201.
[122] See annex IV, paragraph 103, and figure 74.
[123] See annex IV, paragraph 240.

NAPs, namely the integration of adaptation to climate change into other policies.[124] The Adaptation Committee stated that the collaboration in the processes under the three Rio Conventions could materialize in the context of ecosystem-based adaptation in the next workplan of the Adaptation Committee, which is under development.[125]

79. UNEP explained that the term "societally desirable adaptation" in the *Adaptation Gap Report* is based on the contribution of WGII to the AR5 and describes how to move from a level of potential adaptation that is technically and economically feasible to what will actually happen on the ground.[126]

80. The IPCC clarified that the AR5 indicates that while adaptation and mitigation take place at different timescales, we need to work on adaptation, mitigation and development at the same time. UNEP called for the adaptation gap to be kept as small as possible, which will be also achieved through progress in mitigation.[127]

Message 8

The world is not on track to achieve the long-term global goal, but successful mitigation policies are known and must be scaled up urgently

Greenhouse gas emission growth has accelerated, reaching a record high during the decade 2000–2010. The Cancun pledges are only consistent with the long-term global goal with pathways that require a much higher mitigation response later. Moreover, policies in place have had a limited impact on bending the emissions curve downward. However, successful mitigation policies have been identified and progress is being made on scaling them up, in particular in relation to putting a price on carbon and promoting otherwise low-carbon technologies, so that their share becomes dominant. **We need benchmarks for sound climate policy in the light of national circumstances.**

National information was not made available in a balanced manner for consideration by the structured expert dialogue, but such information could be considered in future reviews.

3. Consideration of means of implementation

81. On **technology**, the IPCC, IEA and UNEP experts indicated that many of the technologies required to achieve the 2 °C pathways are already available, but their deployment is not on track for reaching that goal.[128] The required technology deployment is often impeded by social, political and economic barriers rather than technology transfer issues, meaning that the role of social, political and organizational aspects needs to be addressed.[129] In general research and development play a key role in bringing and adjusting existing technologies to local conditions.[130]

82. IEA stressed the need for accelerating innovation in key technologies. In the short term, renewables and energy efficiency would be key in delivering emission savings. Additionally, there is a need for making investments now to ensure that technologies

[124] See annex IV, paragraph 252.
[125] See annex IV, paragraph 254.
[126] See annex IV, paragraph 163.
[127] See annex IV, paragraph 170.
[128] See annex III paragraph 101, and annex IV, paragraphs 107 and 128.
[129] See annex III, paragraphs 101 and 106.
[130] See annex IV, paragraph 107.

related to CCS and end-use fuel switching, including the electrification of transport, will be available when they are needed.[131]

83. The TEC reported on the key milestones in the technology process under the Convention, culminating with the 2010 establishment of the Technology Mechanism, which comprises the TEC and the CTCN. The TEC reported on progress related to the technology needs assessments carried out by Parties and aimed at identifying priorities for mitigation and adaptation technologies.[132] The CTCN reported on progress made towards enhanced action on the development and transfer of technology for action on climate change.[133]

84. IPCC experts noted that the AR5 underlined the importance of enabling environments for technology transfer, including institutional arrangements, and the provision of finance and the capacity to absorb the technologies adapted to each region.[134]

85. **Parties sought clarifications** on barriers to technology transfer, promising negative emission technologies, the deployment of BECCS, and the impact of bioenergy production on food security.

86. Current barriers to technology transfer identified by UNEP include financial barriers, regulatory and legal frameworks, technical barriers to the development and transfer of technology, and institutional and organizational barriers.[135] The World Bank stressed that trade barriers are obstacles to transfer of adaptation technologies.[136] The TEC underscored that factors other than funding are equally important for successfully transferring technologies.[137]

87. The IPCC and UNEP explained that the main promising negative emission technologies are either the sustainable deployment of BECCS, or enhancing land sinks in the agricultural and forest sectors, including by increasing forest cover. The IPCC and IEA added that CO_2 removal technologies are essential because of the need for negative emissions brought about by overshooting (see para. 26 above on the role of negative emissions and para. 56 above on the risks associated with scaling up such technologies).[138]

88. FAO said the impacts of bioenergy on food security are very diverse and depend not only on the area of production of biofuels, but also on the timescale used. In some countries, bioenergy production can have an impact on food prices, but can also drive development, lift people out of poverty and reduce energy poverty.[139]

89. On **capacity-building**, the SBI reported progress made under the Durban Forum on capacity-building and the Dialogue on Article 6 of the Convention, noting that they contribute to: disseminating knowledge by promoting discussions among experts and practitioners; identifying lessons learned; replicating good practices and fostering action towards emission pathways consistent with the 2 °C limit; and fostering education and building capacity for well-informed assessments of the adequacy of the long-term global goal and the overall progress towards that goal.[140]

[131] See annex IV, paragraph 135.
[132] See annex II, paragraph 74.
[133] See annex IV, paragraphs 228–232.
[134] See annex IV, paragraphs 97 and 98.
[135] See annex IV, paragraph 190.
[136] See annex IV, paragraph 190.
[137] See annex II, paragraph 82.
[138] See annex III, paragraphs 115 and 120, and annex IV, paragraph 162.
[139] See annex IV, paragraph 179.
[140] See annex IV, paragraphs 218–225.

90. **Parties sought clarification** on how the CTCN plans to collaborate with the Durban Forum on capacity-building, links between the CTCN and other programmes, and capacity-building projects under the CTCN.

91. The CTCN explained that most of its activities are in capacity-building, which underscores the importance of coordinating the work of the CTCN with the Durban Forum. Additionally, the CTCN helps countries to reformulate their requests for services if they are not clearly defined, carries out an 'incubator programme' for LDCs to help them define and identify their technology problems, and organizes webinars that provide training on specific climate-related technologies.[141] The CTCN is careful not to duplicate capacity-building activities of other bodies, and is looking at working in synergy with the Adaptation Fund on capacity-building and preparedness activities.[142]

92. On **finance**, the IPCC reported that there is no widely accepted definition of climate finance and that overall climate finance is estimated at USD 343–385 billion per year, with public climate finance flows to developing countries amounting to USD 35–49 billion per year and private ones falling in the range of USD 10–72 billion per year.[143]

93. On whether the current levels of climate finance are adequate, the IPCC and the SCF indicated that emission scenarios that limit warming to below 2 °C above pre-industrial levels require resources for addressing climate change to be scaled up considerably.[144] The SCF added that some projections indicate that current spending on 'brown' technologies will continue to grow faster than spending on renewable technologies.[145] Regarding mitigation, IEA reported that investment in energy supply has doubled since 2000 and that investment in renewables was scaled up considerably between 2000 and 2011; however, fossil fuels still dominate energy supply investments.[146]

94. The IPCC, the SCF and UNEP emphasized that although spending on adaptation has increased, the current focus remains on mitigation.[147] UNEP estimated that public finance committed to activities with explicit adaptation objectives was in the range of USD 23–26 billion in 2012–2013, of which 90 per cent was invested in developing countries. Only about 2 per cent of total adaptation finance came from multilateral mechanisms (USD 0.6 billion committed for developing countries in 2013), but this is a largely increasing trend.[148] UNEP underscored the difficulty of distinguishing between finance made available for adaptation and that for development or other purposes.

95. The Adaptation Committee reported that organizations and agencies need to consider their organizational mandates, set-ups and resources in the light of the long-term nature of the NAP process. For many Parties, there is a lack of clarity on procedures for applying for funding for the NAP process. Some Parties therefore suffer from inadequate and unpredictable financing, which hinders the further scaling-up and mainstreaming of adaptation into national development planning. UNEP warned that a major adaptation funding gap is likely, particularly after 2030.[149]

[141] See annex IV, paragraph 235.
[142] See annex IV, paragraph 247.
[143] See annex III, paragraph 178.
[144] See annex II, paragraph 76, and annex III, paragraph 179.
[145] See annex II, paragraph 76.
[146] See annex IV, paragraph 129, and figure 82.
[147] See annex II, paragraph 77, annex III, paragraph 178, and annex IV, paragraph 105.
[148] See annex IV, paragraph 105.
[149] See annex IV, paragraph 104.

96. The GCF reported on work to "move to full scale operations", highlighting that it had reached the target of USD 10 billion in resource mobilization. It also outlined future steps that need to be taken to enable it to start committing resources.[150]

97. **Parties sought clarification** on the range of estimates of public and private climate finance flows, the difficulty of defining adaptation finance, the high percentage of climate flows directed towards mitigation, leveraging private sector finance, and issues related to the operationalization of the GCF.

98. Regarding the definition of climate finance, experts indicated that the debate is still ongoing as to whether climate finance is more than just the incremental finance that drives funds from high-carbon to low-carbon investments.[151]

99. On the finance gap, the World Bank indicated that infrastructure finance is lacking USD 1.0–1.5 trillion per year[152] and that carbon pricing could provide some of the financing needed to achieve the long-term global goal.[153] The GEF highlighted the importance of: mainstreaming private sector engagement in climate financing; market transformation through risk reduction in capital-intensive investment; more efforts to enhance enabling environments through capacity-building and technical assistance; and strengthening efforts to build the necessary support infrastructure and policy frameworks to further scale up technology investment and achieve transformational impact.[154] Private sector finance, which constitutes the largest part of climate finance, is mostly channelled to mitigation.[155]

100. As far as adaptation finance, UNEP clarified that the *Adaptation Gap Report* only includes funding for adaptation that is qualified as "significant" or "principal". This excludes disaster relief, although funding for disaster risk management is increasingly being included in estimates of adaptation finance flows. There are high uncertainties in the cost estimates for adaptation because not much data is available to assess the effect of the measures. Additionally, since private sector adaptation activities cannot be tracked, they are not included in estimates of finance flows.[156]

101. The GCF clarified that it is currently converting pledges by governments into agreements and that the fiduciary information disclosed by entities seeking accreditation with the GCF are treated as confidential.

4. Equity

102. The IPCC noted the importance of assessing the issues of equity, justice and fairness raised by mitigation and adaptation action, including the following: different past and future contributions to the accumulation of GHGs in the atmosphere; different capacities to undertake mitigation and adaptation; and varying challenges and circumstances.[157] Limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication, while taking into account possible risks from mitigation actions and adaptation obstacles of particular relevance for the more vulnerable and disadvantaged.[158]

[150] See annex IV, paragraph 306–308.
[151] See annex II, paragraph 95, and annex III, paragraph 165.
[152] See annex IV, paragraph 159.
[153] See annex IV, paragraph 189.
[154] See annex II, paragraph 78.
[155] See annex III, paragraph 184.
[156] See annex IV, paragraph 185.
[157] See annex IV, paragraph 34.
[158] See annex III, paragraphs 67, 68, 70 and 71, and annex IV, paragraph 47.

103. On equity and equitable effort-sharing in relation to achieving the long-term global goal, the IPCC presented three lines of argument: Parties have accepted legal commitments to act equitably against climate change; it is morally proper to allocate burdens associated with the common global climate challenge according to ethical principles; and equitable effort-sharing will be necessary if the climate challenge is to be effectively met.[159] Furthermore, a cooperative agreement based on effort-sharing that is seen as equitable and based on ethical principles may lead to more effective cooperation, and could reduce the potential risk of costs of climate action constraining development.[160]

104. The IPCC indicated that a regional breakdown of mitigation expenditure based on mitigation potential (i.e. where each region undertakes mitigation up to a common, equal marginal abatement cost) reflects a distribution of costs that is the opposite of what might be expected if the mitigation burden were instead shared according to equity, which is the issue at the core of the effort-sharing problem. Effort-sharing schemes based on ethical principles have the potential to yield a more equitable cost distribution across countries than those based on mitigation potential.[161]

105. **Parties sought clarification** on regional differences in mitigation costs and the assumptions used for their estimation. The IPCC clarified that Africa would have the highest mitigation costs because costs are calculated as a percentage of GDP, which is low in Africa, and because estimates take into account not only present emission levels, but also their projected growth.[162]

Message 9

We learned from various processes, in particular those under the Convention, about efforts to scale up provision of finance, technology and capacity-building for climate action

Many of the technologies required to achieve the long-term global goal are already available, but their deployment is not on track. Various barriers to their deployment and transfer have been identified. There is no widely accepted definition of climate finance, and uncertainties remain in the tracking of climate finance flows, in particular for adaptation finance and private finance, and to a lesser extent also for mitigation finance. Discussions are ongoing in various processes under the Convention regarding the resources required to address climate change under emission scenarios that limit the temperature increase to below 2 °C.

Institutions and processes launched under the Convention on technology and capacity-building have built a foundation for much greater effort, and progress has been achieved in the operationalization of the Green Climate Fund. The level of action now needs to be increased on all fronts.

D. Consideration of strengthening the long-term global goal, including in relation to a temperature rise of 1.5 °C

106. Regarding the strengthening of the long-term global goal, the SED addressed the following: the difference in projected risks of climate impacts between 1.5 °C and 2 °C of warming, in particular in relation to extreme events or tipping points; the regional differences in projected risks of climate impacts between 1.5 °C and 2 °C of warming; and

[159] See annex III, paragraph 173.
[160] See annex III, paragraphs 173, and annex IV, paragraph 34.
[161] See annex III, paragraph 176.
[162] See annex III, paragraph 183.

the feasibility of the 1.5 °C limit, in particular in relation to mitigation scenarios that limit global warming to below 1.5 °C, and the risks associated with such a limit, notably that of overshooting the 1.5 °C limit and the concomitant triggering of climate change accelerating feedbacks.

107. Although literature on the projected risks and impacts at 1.5 °C of warming is limited, IPCC experts made efforts to identify a proxy for the impacts expected at 1.5 °C of warming: using the concept of "one unit of risk",[163] the IPCC indicated that for each key risk, an average of 0.5 additional risk units were estimated for the difference between 1.5 °C and 2 °C of warming above pre-industrial levels. This type of analysis could extract additional information across regions and sectors for these two levels of global warming.[164]

108. Experts emphasized the high likelihood of meaningful differences between 1.5 °C and 2 °C of warming regarding the level of risk from ocean acidification and of extreme events or tipping points, because impacts are already occurring at the current levels of warming; risks will increase with further temperature rise.[165] In particular, experts from the IPCC, SPREP, CCCCC and AMAP indicated that the difference in projected risks between 1.5 °C and 2 °C of warming is significant for highly temperature-sensitive systems, such as the polar regions, high mountains and the tropics, as well as for some other regions, in particular low-lying coastal regions.[166] The IPCC further stressed that regional food security risks are significantly different between 1.5 °C and 2 °C of warming, pointing to the example of Africa, where in some countries the reduction in staple crop yields is projected to be higher than the global average.

109. Experts also underscored that challenges in the understanding of some physical systems, such as glaciers and permafrost, hinder the estimation of projected risks of climate impacts at 1.5 °C versus 2 °C of warming, and that for agricultural and human systems, the difference between a 1.5 °C and a 2 °C temperature rise above pre-industrial levels is becoming increasingly difficult to assess.[167] They added that in the light of the difficulties in predicting the risks of climate change, there is value in taking a precautionary approach and adopting a more stringent target.[168]

110. On the other hand, some benefits of scenarios with 1.5 °C instead of 2 °C of warming were identified and include the following: most terrestrial and marine species would be able to follow the speed of climate change; up to half of coral reefs may remain; sea level rise may remain below 1 m; some Arctic sea ice may remain; ocean acidification impacts would stay at moderate levels; and more scope for adaptation would exist, especially in the agricultural sector.[169]

111. Available mitigation scenarios are characterized by a temperature overshoot and large-scale application of CO_2 removal technologies, immediate mitigation action, a rapid scaling-up of the full set of technologies, and development along a low-energy demand pathway.[170]

[163] Defined as the transition of a risk from one level to the next (e.g. from 'very low' to 'low' or from 'medium' to 'medium-high'). For the caveats regarding the comparison of projected risks and impacts at 1.5 °C and 2 °C of warming, see annex IV, paragraph 57.

[164] See annex III, paragraph 54, and annex IV, paragraph 56.

[165] See annex III, paragraph 54, and annex IV paragraph 204.

[166] See annex III, paragraph 35 and 52.

[167] See annex III, paragraph 54.

[168] See annex IV, paragraph 57.

[169] See annex III, paragraph 53, and annex IV, paragraphs 43 and 56.

[170] See annex III, paragraph 114, and annex IV, paragraph 66.

112. **Parties sought clarification** on: the difference in impacts on both oceans and land of global warming of 1.5 °C and 2 °C above pre-industrial levels; the window of opportunity in relation to a 1.5 °C and a 2 °C temperature rise; the required technologies, their scaling-up, the technology portfolio and the costs related to achieving the 1.5 °C scenarios; the comparison between the increased costs of mitigation, the reduced costs of adaptation and the avoided non-monetary impacts between the 1.5 °C and 2 °C warming limits; and whether overshooting scenarios would increase the risk of carbon cycle feedbacks and ocean acidification.

113. On the **projected risk of climate impacts at 1.5 °C of warming**, the IPCC indicated that near-term risk in a situation with warming of around 1.5 °C could serve as an operational tool to provide an approximate indication of the risks of climate impacts of a long-term warming of 1.5 °C.[171] Some experts warned that current levels of warming are already causing impacts beyond the current adaptive capacity of many people, and that there would be significant residual impacts even with 1.5 °C of warming (e.g. for sub-Saharan farmers), emphasizing that reducing the limit to 1.5 °C would be nonetheless preferable. The CBD secretariat drew attention to the increased risk of extinction when going from 1.5 °C to 2 °C of warming, while noting the uncertainties on how this will happen.[172]

114. In terms of **feasibility, costs and risks** of the 1.5 °C scenarios, the IPCC indicated that overshooting is a typical feature of low-emission scenarios, with its related risks.[173] Higher emission scenarios come with higher risk of feedbacks that accelerate climate change, so keeping the temperature rise below 1.5 °C could help control carbon cycle feedbacks and reduce risks from them.[174] The technologies required for the 1.5 °C scenarios are the same as for the 2 °C pathway, but need to be deployed faster, and energy demand needs to be reduced earlier, implying a higher cost than in the 2 °C scenarios.[175] The IPCC also noted that some technologies and policies required to limit warming to 1.5 °C may negatively impact poverty reduction efforts. However, impacts are already occurring and risks will increase with the degree of temperature rise. In general, pathways limiting warming to below 1.5 °C by the end of the century are similar to those limiting warming to 2 °C, but call for more immediate mitigation action and an additional scaling-up of the challenging features of the 2 °C scenarios, such as the scaling-up of CO_2 removal technologies and of the full set of low-carbon technologies.[176]

115. On the **comparison of costs and avoided** impacts between the 1.5 °C and 2 °C warming limits, the IPCC drew a distinction between mitigation costs and net benefits, noting that cost implications would not determine whether or not to pursue the 1.5 °C warming limit.

[171] See annex II, paragraph 50, and annex III, paragraph 27.
[172] See annex IV, paragraph 244.
[173] See annex III, paragraph 121.
[174] See annex II, paragraph 66.
[175] See annex III, paragraph 151.
[176] See annex IV, paragraphs 60 and 66.

Message 10

While science on the 1.5 °C warming limit is less robust, efforts should be made to push the defence line as low as possible

The science on the 1.5 °C warming limit is less robust than for the 2 °C warming limit or warming beyond this limit. Consequently, assessing the differences between the future impacts of climate risks for 1.5 °C and 2 °C of warming remains challenging. More scientific findings are likely to become available in the future, and considerations on strengthening the long-term global goal to 1.5 °C may therefore have to continue.

Nevertheless, limiting global warming to below 1.5 °C would come with several advantages in terms of coming closer to a safer 'guardrail'. It would avoid or reduce risks, for example, to food production or unique and threatened systems such as coral reefs or many parts of the cryosphere, including the risk of sea level rise. On the other hand, this implies a more pronounced reliance on negative emissions with associated risks, including those from land-use change, as well as increases in mitigation costs in comparison with the 2 °C warming limit, and requires a larger temperature overshoot, which also carries certain risks.

However, while it is unclear whether the difference between 2 °C and 1.5 °C of warming is really only a matter of a gradual increase in risks or also includes some non-linear effects, as some evidence from the palaeo-record indicates,[a] Parties may wish to take a precautionary route by aiming for limiting global warming as far below 2 °C as possible, reaffirming the notion of a defence line or even a buffer zone keeping warming well below 2 °C.

[a] See annex II, paragraphs 38–40, 51 and 67, footnote 51 above, and figure 16.

IV. Concluding remarks and possible next steps

116. The SED sessions brought together many government delegates and experts from all regions, as well as civil society representatives. During each session, we made great efforts to ensure a geographical, gender, regional, institutional balance, as well as to maintain an equilibrium between the two themes of the review (figure 1). We did this both in terms of presentations and the time allocated to the discussions. The discussions were substantial, with Parties and experts engaging in a remarkably constructive and rich dialogue. We believe the productive and informative discussions at SED sessions supported Parties in internalizing the key findings of all the contributions to the AR5 and of the work in the processes under the Convention and of other organizations and regional bodies. We also believe that the SED has proved to be a valuable addition to the science–policy interface in general, as it has informed and supported policy formulation while taking into account various values and recognizing that what constitutes an intolerable risk may differ across sectors, regions and countries. We also consider that the face-to-face conversation with the policymaking community was essential for scoping future assessments of the science of climate change.

117. The SED has shown that limiting global warming to below 2 °C above pre-industrial levels would significantly reduce the projected risks of climate change, allowing, in the light of Article 2 of the Convention, the adaptation of many ecosystems, protecting food production and enabling economic development to proceed more sustainably. However, the SED has also illustrated that, in some regions and vulnerable ecosystems, high risks are projected even for warming above 1.5 °C. We are therefore of the view that Parties would profit from restating the long-term global goal as a 'defence line' or 'buffer zone', instead of a 'guardrail' up to which all would be safe. This new understanding would then probably also favour emission pathways that will limit warming to a range of temperatures below 2 °C. In the very near term, such aspirations would keep open as long as possible the option

of a warming limit of 1.5 °C, and would avoid embarking on a pathway that unnecessarily excludes a warming limit below 2 °C.

118. On theme 2 of the review, the SED has clearly shown that not only are we not on track to meet the long-term global goal, but the current emission rate is accelerating. It seems advisable, including according to the many experts consulted, to scale up current mitigation, adaptation, finance, technology and capacity-building efforts so as to enable all Parties to reach the long-term global goal. To that end, emissions need to be cut significantly and immediately, in particular to minimize effort and keep it cost-effective. Additionally, since carbon neutrality should be achieved in the second half of this century in the light of the limited global CO_2 budget, prompt and decisive climate action is needed. To address equity issues and make progress in reducing poverty in general, efforts need be strengthened to promote sustainable development in ways that minimize impediments from climate change by promoting mitigation as well as adaptation in an appropriate and well-balanced manner and always taking into account national circumstances.

119. Looking at future reviews, we hope that the work done by the SED under the 2013–2015 review will inspire future work of a similar nature. More specifically, the next review is expected to make use of the more complete national information contained in reports from Parties and other processes under the Convention, since all of the reports from the measurement, reporting and verification process are scheduled to be available by 2017. Therefore, the next review could bring together the best available knowledge not only from the scientific community, but also from national information sources.

120. Furthermore, the SED has identified that gaps in relevant knowledge exist for various regions, especially vulnerable ones such as Africa, the Pacific, the Caribbean and the Arctic. The SED has also highlighted various other vulnerable areas where additional research and discussions are required in order to better inform policymakers on the adequacy of the long-term global goal and overall progress made towards it. Such topics include: the evaluation of the costs of adaptation; the value assessment of the co-benefits of climate change mitigation; the relationship between ocean acidification and temperature increase; a broader and scientifically more robust assessment of the 1.5 °C warming limit; the impacts of climate variability and extremes on crop yields; the impacts of climate change on nutrition, livestock and marine fisheries, as well as on pests and diseases; and human health issues such as desert dust as a climate forcer.

121. Within the global risk management framework, it is clear that we need to link the cycle of assessments of the adequacy of the long-term global goal and the progress made towards achieving it with other processes and assessment cycles, as is for example done under the Ad Hoc Working Group on the Durban Platform for Enhanced Action. Such a cycle could include a consideration of the next IPCC products. The SED could reconvene to consider both these future reports and the national information that will become available by then.

122. We hope that the work of the SED has informed Parties by providing the best available scientific knowledge, that it was guided by the principles of equity and common but differentiated responsibilities and respective capabilities, and that it took into account the relevant principles and provisions of the Convention. We also hope that we have enabled Parties to make well-informed decisions on the adequacy of the long-term global goal and on the measures and means of implementation needed to make good progress towards achieving this goal. We, the co-facilitators, hope to have served us all on our challenging journey towards a future with minimal dangerous interference with our planet's climate system.

Annex I

Summary report on the first structured expert dialogue on the 2013–2015 review

I. Introduction

A. Mandate

1. In response to the mandates provided in decisions 2/CP.17 and 1/CP.18, the Chairs of the Subsidiary Body for Scientific and Technological Advice (SBSTA) and the Subsidiary Body for Implementation (SBI) sent a joint message to Parties, on 11 March 2013, signalling the intention to organize an in-session workshop on the 2013–2015 review (hereinafter referred to as the review) at the thirty-eighth sessions of the subsidiary bodies and inviting Parties to submit their views on the available information that should be considered at that workshop.[1] The secretariat received six such submissions from Parties and two from non-governmental organizations (NGOs).[2] On the basis of the mandate for the review and the aforementioned submissions from Parties, the Chairs of the SBSTA and the SBI provided an informal note that outlined the organization and goals of the workshop.[3]

B. General objectives

2. The objectives of the workshop were to increase the understanding of existing scientific knowledge and explore how it could be used to address the two themes of the review: (i) the adequacy of the long-term global goal in the light of the ultimate objective of the Convention; and (ii) overall progress made towards achieving the long-term global goal, including a consideration of the implementation of the commitments under the Convention.[4]

II. Summary of the proceedings

3. The workshop was held on 5 June 2013 at the Maritim Hotel in Bonn, Germany, during the thirty-eighth sessions of the subsidiary bodies, and it was open to all Parties and observers. The discussions at the workshop focused on the two themes of the review described in paragraph 2 above. Additional information on the workshop, including the agenda for the workshop and copies of all presentations, is available on the web page of the structured expert dialogue (SED).[5]

4. The workshop was opened by Mr. Richard Muyungi, Chair of the SBSTA, and was facilitated by Mr. Zou Ji (China), one of the co-facilitators of the SED.

5. Under the first theme of the workshop, views were sought on possible ways to assess the adequacy of the long-term global goal using various sources of information. Three experts, from the World Meteorological Organization (WMO), the Intergovernmental Panel on Climate Change (IPCC) and the Hadley Centre, made presentations. The co-facilitator then provided the following guiding questions:

[1] <http://unfccc.int/files/parties_and_observers/notifications/application/pdf/message_to_parties_from_the_sbsta_and_sbi_chairs_2013_2015_review.pdf>.

[2] Available at <http://unfccc.int/7590.php>.

[3] <http://unfccc.int/files/methods_and_science/research_and_systematic_observation/application/pdf/informal_note_14_may_2013.pdf>.

[4] See decision 1/CP.18, paragraph 79.

[5] <http://unfccc.int/science/workstreams/the_2013–2015_review/items/8477.php>.

(a) How could IPCC information be used to carry out the review? How could such information be complemented by national and regional information, taking into account any concerns relating to the reopening of the IPCC findings?

(b) How could information from other relevant reports from United Nations agencies and other international organizations be used in the review?

(c) What technical work should be undertaken under the SED to assess the adequacy of the 2°C goal? Which analytical frameworks could be used to assess the impacts and risks of the 2 °C goal?

6. Reflecting on the questions above, representatives of the Alliance of Small Island States (AOSIS), European Union and Switzerland gave presentations, followed by an open discussion.

7. The deliberations under the second theme of the workshop were initiated by a scene-setting presentation made by the secretariat. The co-facilitator then introduced the following guiding questions:

(a) How could information from the IPCC, Parties and United Nations agencies and other international organizations be used in the review?

(b) Which institutions, bodies and processes could provide relevant information to the review?

(c) What technical work should be undertaken under the SED to assess the overall progress made towards achieving the long-term global goal, without duplicating the work of the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP)?

8. Reflecting on the questions above, representatives of China, Philippines and New Zealand gave presentations, followed by an open discussion.

9. On the NGO side, a representative of Climate Action Network-International made a statement. The proceedings of the workshop were broadcast on the Web, and social media were used to increase the participation of Parties and observers outside the workshop venue.

10. At the closing the workshop, the co-facilitator thanked Parties for their constructive discussions and the NGOs for their contribution.

III. Summary of the workshop discussions

A. Theme 1: the adequacy of the long-term global goal in the light of the ultimate objective of the Convention

1. Presentations by experts and Parties' reflections

11. The first presentation, by Mr. Jerry Lengoasa (WMO), focused on the status of the global climate, drawing on the recent publication of the WMO statement on the status of the global climate in 2012.[6] He described the observed changes in the physical system, showing upward trends in the anomalies for global temperature, in sea level, humidity and ocean heat content and downward trends in the extent of sea ice, glacier mass balance and area of snow cover.[7]

12. He noted the following: a daily carbon dioxide (CO_2) concentration of above 400 ppm was reported in 2012 by the Global Atmosphere Watch stations; the global land and ocean surface temperature was estimated to be 0.45 °C±0.11 °C above the 1961–1990 average of 14 °C; the years 2001–2012 were all among the top 13 warmest years on record; and the Arctic sea ice extent in 2012 showed the largest seasonal loss on record. He underlined the importance of the essential climate variables[8] in supporting the exchange of information, and also

[6] <http://library.wmo.int/pmb_ged/wmo_1108_en.pdf>.

[7] The presentation by Mr. Chris Field of IPCC (see paras. 13 and 14 below) emphasized that the changes in the Earth system are consistent with climate change.

[8] The variables cover the oceanic (18 variables), atmospheric (14 variables) and terrestrial (16 variables) domains.

noted that a substantial number of national climate records in temperature and precipitation were renewed and that a very high impact of extreme climate events was recorded in 2012, including heatwaves, drought and floods.

13. The second presentation was made by Mr. Chris Field (IPCC) on the IPCC assessments and their possible use to assess the long-term global goal, with a special focus on dangerous anthropogenic interference. He highlighted that an assessment of what constitutes such interference must involve value judgements that go beyond the methods and insights of science. He suggested that the following four elements be included in the consideration of dangerous anthropogenic interference: the level of impacts to avoid; for which future world; with what probability that the impact will occur; and for which stakeholders. These elements are interconnected. For example, uncertainties mandate a risk management perspective, which requires an agreement on the probability of avoiding a given level of impact. Likewise, different future worlds will have an impact on the vulnerability of a given stakeholder, owing, for example, to variation in wealth, equity, infrastructure and institutions.

14. In addition, Mr. Field explained the core elements of the IPCC Fifth Assessment Report (AR5), including the use of risk-based framing, the presentation of impacts for a wide variety of possible futures and climate outcomes, the thorough description of uncertainty, and awareness of interactions and potential surprises. The presentation underlined the increase in the sensitivity of the system due to observed impacts of climate change (e.g. on wildfires and agricultural yields) and provided examples of recently observed extreme climate events, suggesting whether or not they were caused by climate change. It also illustrated the effect of increases in global average temperature on the risks to unique and threatened systems, on large-scale discontinuities and extreme weather events, as well as on aggregated impacts and the distribution of impacts.

15. Mr. Jason Lowe (Hadley Centre) said that the feasibility of limiting warming is influenced by the response of the climate system,[9] economic and technology development and the capabilities of policies and markets to create a situation favourable to emission reductions. He then illustrated the relationship between the global emission reduction rate per year and the time frame for the peaking of global emissions[10] for emission pathways compatible with a 50 per cent probability of limiting warming below 2 °C in 2100. He concluded that a late peaking would require negative emissions and would lead to potential competition for land between biofuels and food production,[11] and that there is still a 50 per cent probability of limiting warming below 2 °C without negative emissions, but the window of opportunity is narrow. He also stated that a 1.5 °C target would be possible with a lower probability or a temperature overshoot, and he questioned whether the resilience for such a target with overshooting could be treated in the same way as targets without overshooting, considering the limited science on temporary resilience.

16. Mr. Lowe highlighted the benefits of achieving the 2 °C goal compared with 'business as usual', such as reducing the number of people suffering as a result of the stress on water resources and river and costal floods, increasing spring wheat productivity, reducing the acidification of the oceans, and reducing the energy requirements for cooling. He noted that the estimated percentage of avoided impacts for 2 °C compared with 4 °C varies for the above examples and that these estimated percentages are relatively robust to the uncertainty of climate modelling compared with the uncertainty for absolute avoided impacts. He also noted that large-scale climate system thresholds may be affected by more than temperature,[12] underlined the significant role that the interactions among these thresholds might have on the overall risk of abrupt climate change, and suggested the application of multiple temperature targets, each with a separate probability (e.g. a 50 per cent probability of limiting temperature rise to less than 2 °C and a 90 per cent probability of limiting temperature rise to less than 4 °C).

[9] Temperature response to a given emission pathway.

[10] Based on climate-modelling results from the AVOID (Avoiding Dangerous Climate Change) programme (see <http://www.metoffice.gov.uk/avoid/what-is-avoid>).

[11] For example, a global emission reduction rate of 2–4 per cent could result in emissions peaking between 2015 and 2020, for cumulative emission budget by 2100 of between 0 and 200 Gigatonnes of CO_2.

[12] For example, the dieback of tropical forest is affected by the CO_2 concentration, as well as the length of the dry season, while the overturning of the Atlantic Ocean is affected by the atmospheric concentration of aerosols.

17. A representative of AOSIS stressed that the technical work to be undertaken should include an assessment of impacts and risks at different levels of CO_2 concentration and warming, including 1.5 °C, especially the risks of ocean acidification, global and regional sea level rise and irreversible changes in the physical, ecological and human systems, including for specific regions and key sectors and systems. Observations and projections relevant to local and regional circumstances should cover exposure and vulnerability to climate change, the resulting impacts, adaptation options and loss and damage.

18. In addition, he underlined that the SED should also consider current and near-term emission trends and global emission pathways, including target emission levels and budgets for achieving the long-term global goal with high probability; associated costs of, and technological options for, mitigation pathways; and the issues relating to the response of the climate system, such as climate sensitivity, the global carbon cycle, non-CO_2 forcing and climate projections. Regarding the issue of the use of information, he noted that, in addition to IPCC information, information from United Nations agencies and other international and regional organizations should be used in the review (see the appendix), in particular with regard to research findings for smaller countries, such as small island developing States and the least developed countries.

19. A representative of the European Union further elaborated on the risks at different levels of warming and evaluated those risks as manageable through adaptation for a temperature rise of 1–2 °C, significant for a 2–3 °C rise, and potentially disastrous for a 3–4 °C rise, on the basis of the species extinction rate, impact on food production, additional people exposed to water stress and the response of the climate system.[13] Regarding the global emission pathways, he suggested considering the probability of achieving the 2 °C goal, noting that for a 50 per cent probability, emissions should peak at 500 ppm CO_2 eq and stabilize at 450 ppm, while for a 75 per cent probability they should peak at 475 ppm and stabilize at 400 ppm.

20. A representative of Switzerland was of the view that Article 2 of the Convention indicates which scientific inputs should be considered by the SED (e.g. greenhouse gas concentration, dangerous anthropogenic interference with the climate system, ecosystems, food security and economic development in a sustainable manner) and he illustrated the danger of 'cherry-picking' data and literature on climate science. He then stressed that the IPCC provides the best scientific input and, therefore, should be the foundation for the review.

2. Discussions

21. Responding to the presentation made by the IPCC, a participant welcomed the approach of a risk-management framework and underscored that all available information, including regional information, should be taken into account when a value judgement is going to be made under the review. In addition, with regard to the presentation made by the representative of the European Union, she asked for the rationale for distinguishing manageable risks and significant risks, and whether such risks are perceived as global or regional. Furthermore, responding to the Swiss representative's presentation, she noted that regional information is as important as IPCC information.

22. Another participant explained her interpretation of the objective, principles and scope of the review and stressed the need for balance between the two themes. She noted that the adequacy of the long-term global goal is not only an issue of the number for the goal but also an issue of its context. Her views were supported by another participant, who stated that an integrated approach, assessing mitigation, adaptation and economic, social and political conditions, is needed to conduct the review. He also stressed that the assessment of what has to be done under the Convention to achieve the 2 °C goal is important.

23. Most Parties underlined the important role of science in the review. Some Parties stated that IPCC findings will be key information and that regional and national information could supplement the IPCC information, while others were of the view that regional and national information should be regarded as being at the same level as IPCC information.

[13] EU Climate Change Expert Group 'EG Science'. 2008. The 2 °C target: Background on Impacts, Emission Pathways, Mitigation Options and Costs, available at <http://ec.europa.eu/clima/policies/international/negotiations/future/docs/brochure_2c_en.pdf>.
Eric Fee (Ed.) 2010. Scientific Perspectives after Copenhagen, available at <http://www.eutrio.be/files/bveu/media/documents/Scientific_Perspectives_After_Copenhagen.pdf>.

B. Theme 2: overall progress made towards achieving the long-term global goal, including a consideration of the implementation of the commitments under the Convention

1. Presentations by experts and Parties' reflections

24. An introductory presentation was made by the UNFCCC secretariat on information gathering for the assessment of the overall progress made towards achieving the long-term global goal. After outlining the main sources of information for the review, he focused on information from Parties,[14] which he grouped into three categories, namely: submissions; national reports, including international assessment and review (IAR) and international consultation and analysis (ICA) reports; and information from other relevant reports from Parties and processes under the Convention. Regarding national reports, he stressed a possible issue relating to the date of publication of IAR and ICA reports, which will be available from 2014 and 2015, respectively. With regard to the above-mentioned other processes, he noted the need to identify processes that would be relevant to the review.

25. A representative of China was of the view that the objectives of the review are to facilitate the achievement of the ultimate objective of the Convention and to provide useful input to the ADP and various institutions under the Convention. After presenting his understanding on how the principles and provisions of the Convention would guide the review, he noted that the review is not a review of the Convention itself and suggested its focus should be on assessing the implementation of the commitments under the Convention. With regard to elements that should be addressed under theme 1, he mentioned the impacts of the 2 °C goal on ecosystems, the environment and social and economic aspects; adaptation costs; the impacts of mitigation efforts on developing countries; and current knowledge on alternative goals. In relation to theme 2, he mentioned the adequacy and implementation of mitigation commitments of Parties included in Annex I to the Convention (Annex I Parties), the provision of means of implementation by Parties included in Annex II to the Convention (Annex II Parties), and adverse social and economic impacts of the implementation of mitigation commitments on developing countries.

26. Regarding the use of information, he acknowledged that the IPCC is one of the key information sources and suggested that high priority should be given to information from Parties. He also stated that information from United Nations agencies and from existing institutions, bodies and processes is also important and complementary to the IPCC information. Regarding the technical work to be conducted under the SED, he suggested updating the information on financial and investment flows on the basis of previous work,[15] and the technology needs of developing countries on the basis of a new round of technology needs assessments.[16] He also provided some questions to be addressed, including on the emission trends of Annex I Parties and on the technology and financial needs of developing countries.

27. A representative of the Philippines supported the views presented by the representative of China and presented an integrated contextual framework for the review, which suggested that the implementation of the Convention should be the basis for assessing the progress on mitigation and adaptation towards achieving the LGTT. He illustrated that the level of progress will influence the amount of time available to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner, and will consequently determine the adequacy of the 2 °C goal. He provided questions corollary to the key assessment questions for the two themes of the review (e.g. is the 2 °C goal adequate? Is overall progress being made towards achieving the 2 °C goal?[17]) and suggested categories of information that will be needed to carry out the review.

28. Regarding the technical work to be conducted under the SED, he suggested assessments of implementation advances and gaps; incentives for, and barriers to, the implementation of commitments; the

[14] Decision 2/CP.17, paragraph 161(b), specifies the types of information received from Parties that should be included in the review.

[15] See <http://unfccc.int/resource/docs/2008/tp/07.pdf>.

[16] See <http://unfccc.int/ttclear/templates/render_cms_page?TNA_home>.

[17] For example, linked to the implementation of Article 4, paragraph 1(a), (b) and (d), paragraph 2(a) and (b), and paragraphs 3, 4, 5 and 7, of the Convention.

impacts of, and responses to, the implementation of commitments; and linkages and feedback loops arising from the implementation of commitments.

29. A representative of New Zealand, speaking on behalf of Australia, Canada, Japan, New Zealand, Norway and the United States of America, presented a view different from the two preceding presentations on elements to be discussed as part of the SED under theme 2, drawing on the mandate of the review to assess aggregate progress and the actions of all Parties. This involves assessing aggregate GHG emissions, trends and projections; the effectiveness of mitigation actions undertaken by all Parties; the aggregate mitigation commitments of all Parties and progress towards achieving those commitments; the implementation of commitments under the Convention; economic circumstances and capabilities of Parties; and cost-effective mitigation potential, clean energy technology and energy efficiency potential.

30. She suggested the following approach to the technical work under the SED: to discuss the findings of the IPCC, when available; to compile inputs into synthesis reports; and to keep it an open space in which to explore the best ways for the global community to achieve and maintain the long-term global goal. She also stressed the important role of information regarding the implementation of transparency provisions, including biennial reports and biennial update reports, and the role of the secretariat in compiling and systemizing information on progress, under the guidance of the co-facilitators of the SED.

2. Discussions

31. Responding to the proposal for an assessment of the commitments of developed country Parties, several participants commented that the global picture of the long-term global goal should be maintained in the review. Another participant suggested that the review should not duplicate work that is being undertaken elsewhere in the UNFCCC process.

32. Additional inputs by other participants included the following:

(a) Emphasized that the assessment of IPCC information is the starting point for the review and that such information should be supplemented by national and regional information, especially when large-scale data are interpreted for developing a policy on a small spatial scale;

(b) Explained their understanding of the long-term global goal, which is not just a simple temperature goal, but also includes goals for adaptation, technology and finance, and underlined that assessing the overall progress towards achieving the long-term global goal implies an assessment of the means of implementation provided, as implementation of actions will depend on the scale of the means of implementation;

(c) Stressed the importance of balance between the two themes of the review and suggested inviting IPCC experts on sustainable development, equity, investment and finance to make presentations under theme 2, and supported the view presented by the representative of China that the review is not a review of the Convention itself;

(d) Pointed out that reviewing finance or technology support will be understood as a review of the Convention. She noted that the decisions of the COP on the review make no reference to groups of Parties, and she stressed that the overall progress made by Parties encompasses all Parties' efforts towards achieving the long-term global goal.

33. Regarding the 'other processes'[18] to be considered in the review, one participant suggested that relevant outputs of processes under the Convention, such as on long-term finance, response measures and work done under the Nairobi work programme on impacts, vulnerability and adaptation to climate change, should be fed into the review. He also suggested that the consideration of inputs from IPCC AR5 should start after the completion and adoption of its reports.

[18] See paragraph 24 above.

C. Virtual participation

34. Participants who were not at the workshop venue were able to watch the event online via webcast and offer reactions, views or questions as input to the discussion on Twitter. Over 300 tweets were sent out by 140 contributors, reaching 230,000 people, including on the following:[19]

(a) The extent of avoided impacts in the 2 °C or 1.5 °C target scenarios;

(b) The implication for risks if the global emissions do not peak by 2020;

(c) The need to consider information from the International Energy Agency and World Bank publications (e.g. *World Energy Outlook*);

(d) The role of science, including what is dealt with in the political negotiations, what leads to action and what needs more awareness;

(e) The methodology to decide whether the 2 °C goal is adequate;

(f) The role of observers.

IV. Reflections

35. It is our perception that the discussions revealed some substantive and procedural issues that we should consider when preparing for the next meeting of the SED, including regarding the consideration of the forthcoming contribution of Working Group I to the AR5, which will be relevant to both themes of the review.

36. Regarding the approach to the review, most Parties stressed the need for balance between the two themes, in terms of their consideration in parallel, the time allocated to them, the format of activities, and the experts and panellists invited from developed and developing countries; while some Parties were of the view that the next SED meeting should focus on either theme 1 or theme 2.

37. The expert presentations on theme 1 underlined some issues that require further consideration, including:

(a) The trends in observed changes in the physical system, in particular in relation to the atmosphere (e.g. temperature and precipitation), oceans, cryosphere and sea level, including observations relevant to local and regional circumstances, the consideration of which should cover exposure and vulnerability to climate change, the resulting impacts, adaptation options and loss and damage;

(b) The elements to consider when making a value judgement on the adequacy of the 2 °C goal, the use of risk-based framing, and the assessment of the risks of ocean acidification, global and regional sea level rise, and irreversible changes in physical, ecological and human systems, including for specific regions and key sectors and systems. Some Parties stressed that regional assessment should be covered in the review, especially regions that are less studied in the existing climate science literature;

(c) The feasibility of limiting warming, how to treat temperature overshooting and the benefits of achieving the 2 °C goal compared with 'business as usual', as well as current and near-term emission trends and global emission pathways, including target emission levels and budgets for achieving the long-term global goal with high probability.[20]

38. Parties had an initial exchange of views on the adequacy of the long-term global goal for preventing dangerous anthropogenic interference with the climate system and the feasibility of this goal within given socioeconomic and technical constraints. Parties' views differed on whether the feasibility of limiting warming, including in relation to current and near-term emission trends and global emission pathways, should be

[19] A summary of the Twitter discussion is available at <http://adoptanegotiator.org/2013/06/05/fcccreview-bringing-science-back-into-the-climate-talks>.

[20] The report of Working Group I will contain emission pathways that are likely to limit warming to below 2 °C or 1.5 °C above pre-industrial levels by 2100.

addressed under theme 1. The effects of the LGTT on helping to streamline global efforts to reduce greenhouse gas emissions and inspire national regional and local initiatives could be another aspect to take into account.

39. The presentations on theme 2 underlined a few issues that require further consideration, including:

(a) The identification of inputs from other relevant processes, referred to in decision 2/CP.17, paragraph 161(b), as one of the sources of information specified in decision 2/CP.17, paragraph 161;

(b) The information base that will help with the assessment of overall progress towards achieving long-term global goal, including information from the forthcoming IPCC AR5 reports, from Parties and from other United Nations agencies and international organizations, and from regional and subregional agencies;

(c) The approach to assess the overall progress towards achieving the long-term global goal, including a consideration of the implementation of the commitments under the Convention. Some Parties were of the view that the implementation of the commitments under the Convention, including of the mitigation commitments of Annex I Parties and of the commitments for provision of financial resources, transfer of technology and capacity-building by Annex II Parties, should be the basis for assessing progress on mitigation and adaptation towards achieving the long-term global goal, while other Parties were of the view that the review should assess the efforts made by all Parties, considering the implementation of the commitments under the Convention only when needed to assess overall progress.

Appendix

Specific information sources suggested for consideration under the structured expert dialogue[1]

1. Assessment and special reports and technical papers of the Intergovernmental Panel on Climate Change:[2]

- International Panel on Climate Change *Special Report on Renewable Energy Sources and Climate Change Mitigation* (2011).

2. Other relevant reports from Parties and processes under the Convention

- Technology needs assessment reports;
- Technical paper on investment and financial flows to address climate change: an update.

3. Other relevant reports from United Nations agencies and other international organizations, including reports on emission projections and technology development, access, transfer and deployment, and reports on gross domestic product, including projections, such as from:

- The Food and Agriculture Organization of the United Nations;
- The World Bank;
- The United Nations Environment Programme;
- The International Arctic Science Committee;
- The International Ocean Carbon Coordination Project;
- The International Human Dimensions Programme on Global Environmental Change;
- The International Energy Agency;[3]
- The Earth System Science Partnership;
- The World Climate Research Programme;
- The International Geosphere–Biosphere Programme;
- The World Economic Forum.[4]

4. Scientific information on the observed impacts of climate change, including from reports coordinated by relevant regional and subregional agencies, such as:

- The South Pacific Regional Environment Programme;
- The Caribbean Community Climate Change Centre;
- The University of the West Indies;
- The University of the South Pacific.

[1] This is an initial list of information sources specifically mentioned by Parties during the workshop. For further updates please consult the structured expert dialogue website at <http://unfccc.int/science/workstreams/the_2013-2015_review/items/6998.php>.

[2] Categories 1–4 in this annex reflect the categories of information sources defined in decision 2/CP.17, paragraph 161.

[3] International Energy Agency. 2012. *Energy Technology Perspectives*. Available at <http://www.iea.org/w/bookshop/add.aspx?id=425>.

[4] World Economic Forum. 2013. *Global Risks 2013*. Available at <http://www.marsh.pt/documents/WEF_GlobalRisks_Report_2013.pdf>.

Annex II

Summary report on the second meeting of the structured expert dialogue

I. Introduction

A. Mandate

1. The Conference of the Parties (COP), at COP 18, decided that the structured expert dialogue (SED) should consider on an ongoing basis, throughout the 2013–2015 review, the material from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) as it becomes available, through regular scientific workshops and expert meetings and with the participation of Parties and experts, particularly from the IPCC.[1]

2. The COP, at the same session, also decided that workshops will be open to all Parties and observers, held pre-sessionally, where possible, and organized by the secretariat.[2]

3. In response to these mandates, we sent a message to Parties, on 26 September 2013, indicating our intention to convene the second meeting of the SED (SED 2) to consider the contribution of Working Group I to the Fifth Assessment Report, *Climate Change 2013: The Physical Science* (AR5 WGI), and other information in conjunction with the thirty-ninth sessions of the subsidiary bodies, in Warsaw, Poland; the broad proposed approach to the meeting; and our intention to provide them with an information note outlining that approach.[3] In addition, we invited views on the further work of the SED. The secretariat received four submissions of views from Parties, which we took into account when preparing our approach for SED 2.

B. General objective and approach for the meeting

4. The objectives and goals of SED 2 were to discuss the latest findings, mostly on the basis of AR5 WGI, as they provide a foundation to assess the adequacy of the long-term global goal; to assess the overall progress made so far towards achieving the long-term global goal, as well as the projected progress, including the likelihood of limiting global warming below 2 °C; and to share lessons learned on the effectiveness of the support provided.

5. Accordingly, we organized SED 2 as a fact-finding exchange of views between experts and Parties. IPCC experts presented findings from AR5 WGI and their relevance to both themes of the 2013–2015 review. Representatives of Technology Executive Committee (TEC), Standing Committee on Finance (SCF) and the Global Environment Facility (GEF) presented lessons learned from providing support in technology, finance and capacity-building. A moderated discussion followed addressing guiding questions and questions from all participants.

II. Summary of the proceedings

6. The meeting was held on 12 and13 November 2013 (3–6 p.m. on both days) at the National Stadium in Warsaw, during the thirty-ninth sessions of the subsidiary bodies, and it was open to all Parties and observers.

7. The discussion at the meeting focused on the two themes of the review: the adequacy of the long-term global goal in the light of the ultimate objective of the Convention (theme 1), and overall progress made towards achieving the long-term global goal, including a consideration of the commitments under the Convention (theme

[1] Decision 1/CP.18, paragraph 86(a).
[2] Decision 1/CP.18, paragraph 87(a).
[3] Available at <http://unfccc.int/7803.php>.

2). Theme 2 was considered in two parts: global greenhouse gas (GHG) emissions and concentrations; and lessons learned from providing support in technology, finance, and capacity-building.

8. Each session consisted of three parts: (i) presentations by experts (outreach), (ii) group discussions between experts and Parties, and (iii) general discussion with all participants.[4]

9. The meeting was opened and facilitated by Mr. Andreas Fischlin and Mr. Zou Ji, the co-facilitators of the SED. We commenced with a scene-setting presentation made by an IPCC expert on the overarching findings and new approaches of AR5 WGI. The following questions were provided by the co-facilitator to guide the general discussion:

(a) What are the key messages from AR5 WGI relevant for the review?

(b) What does AR5 WGI tell us about the relationship between GHG emissions, atmospheric concentrations and change in the climate system?

(c) How reliable are the projections made using climate models (e.g. equilibrium/transient, timeline of 2100–2300)?

10. Under the first theme of the review, three experts from the IPCC and an expert from the Netherlands Environmental Assessment Agency (PBL), representing the Integrated Assessment Modeling Consortium (IAMC), made presentations. These experts, together with representatives of the European Union, New Zealand, South Africa, the Alliance of Small Island States (AOSIS) and the IPCC secretariat, reflected on the following questions:

(a) What changes has the world observed, and what changes are projected to be observed, that are related to anthropogenic climate change?

(b) Are there any limitations in working only towards a temperature target? Are there any risks associated with this (e.g. misunderstanding uncertainties in climate sensitivities)?

(c) What uncertainties remain? What is the importance of these? Are they significant enough to affect the global response at the policy level?

11. The general discussion was guided by following questions:

(a) What insights exist on the observed and projected changes in the climate system?

(b) What insights exist on the long-term aspects of climate change?

(c) What are the key findings contained in AR5 WGI on the stabilization level of GHG concentrations in the atmosphere that would prevent dangerous anthropogenic interference with the climate system, and what are the associated uncertainties?

(d) How do the above findings relate to the adequacy of the long-term global goal in the context of policymaking under the UNFCCC?

12. Under the first part of the second theme of the review, two experts from the IPCC made presentations. These experts, together with the other two experts from the IPCC, as well as representatives of Brazil, China, European Union, Switzerland and the IPCC secretariat, reflected on the following questions:

(a) What are the uncertainties and the risks associated with specific pathways and how to address them in the context of decision-making? How urgently is action required to move towards and follow emission pathways compatible with the long-term global goal?

(b) How to deal with issues, such as probabilities, overshooting, negative emissions, and irreversible changes?

(c) What information is most necessary to give an accurate picture of global emissions and progress towards the goal?

[4] Additional information on SED 2, including the agenda for the meeting and copies of all presentations, is available at <http://unfccc.int/7803.php>.

13. The general discussion under the first part of theme 2 was guided by the following questions:

(a) What does AR5 WGI tell us about the overall progress made so far and the projected progress towards achieving the long-term global goal?

(b) What is the relationship between global emissions and the global temperature rise and how can this be factored into policymaking under the UNFCCC?

14. Under the second part of the second theme of the review, representatives of the TEC, the SCF and the GEF made presentations. These experts, together with representatives of AOSIS, Mexico, Philippines and the Climate Technology Centre and Network (CTCN), reflected on the following questions:

(a) How effective have finance, technology transfer, and capacity-building been in supporting the delivery of mitigation and adaptation outcomes? Which supporting schemes have been successful? Are there some best practice examples of streamlining support to lead to effective mitigation?

(b) What are the best practices/lessons learnt in streamlining support that can lead to effective mitigation of and adaption to climate change? Globally, are there any sectors/gases/policies that are 'low-hanging fruit'?

15. The general discussion under the second part of theme 2 was guided by the following questions:

(a) Which scheme of support has worked and for what reasons?

(b) How can best practices and lessons learned be factored into policymaking under the UNFCCC?

16. At the closing of the meeting, the co-facilitators thanked Parties and experts for their constructive and active participation and for their contribution.

III. Summary of the discussion

A. Setting the scene for the consideration of the contribution of Working Group I to the Fifth Assessment Report

1. Presentations by an expert

17. Mr. Thomas Stocker, a co-chair of Working Group I of the IPCC (WGI), presented the overarching findings and new approaches of AR5 WGI relevant for the review. He identified the following three key messages:[5] observed changes in the climate system, based on multiple lines of evidence, show that the **warming of the climate system is unequivocal** (figure 11); based on the understanding of the climate system and its recent changes, **human influence on the climate system is clear** (figure 12); and projections of future climate change indicate that **limiting climate change will require substantial and sustained reductions of GHG emissions** (figure 13).

18. Regarding the first key message, he noted that the global average surface temperature[6] shows a **warming of 0.85** [0.65–1.06][7] °C over the period 1880–2012 and that the observed warming from 1850–1900 to the **reference period 1986–2005 is 0.61** [0.55–0.67] °C. On the last key message, he underlined that CO_2 emissions from fossil fuels released 375 gigatonnes of carbon (GtC) to the atmosphere from 1750 to 2011, while deforestation released 180 GtC, resulting in cumulative anthropogenic emissions of 555 [470–640] GtC. The period 1870–2011 alone accounts for the amount of 515 [445–585] GtC.

[5] See also the headline statements from the AR5 WGI summary for policymakers (SPM), which highlights the overarching conclusions from the SPM in AR5 WGI, at <http://www.ipcc.ch/news_and_events/docs/ar5/ar5_wg1_headlines.pdf>.

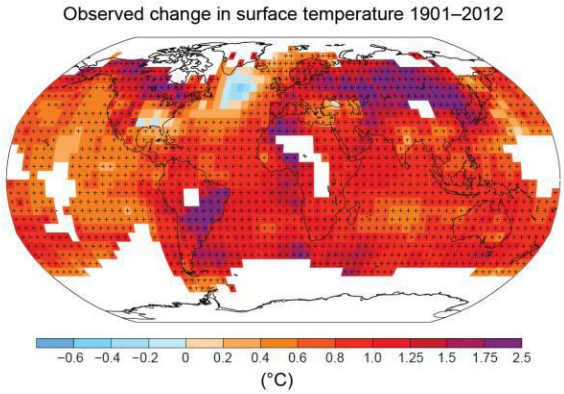
[6] Calculated by a linear trend.

[7] Numbers in brackets give the 90% uncertainty intervals for the best estimate value stated. This interval is expected to have a 90% likelihood of covering the true value that is estimated. These intervals are not necessarily symmetric about the corresponding best estimate.

19. Regarding the relationship between GHG emissions, atmospheric concentrations and change in the climate system, Mr. Stocker noted that the increase in GHG concentrations in the atmosphere and the resulting changes in radiative forcing had an effect on the energy balance of the Earth. As **the total radiative forcing is positive**, it has led to an **uptake of energy in the climate system;** and more than 90 per cent of the energy accumulated between 1971 and 2010 has been **absorbed by the oceans, leading to their warming**. The **largest contribution** to the radiative forcing **is caused by the increase in the atmospheric concentration of CO_2** and these **changes are clearly due to the human influence on the climate system**.

Figure 11

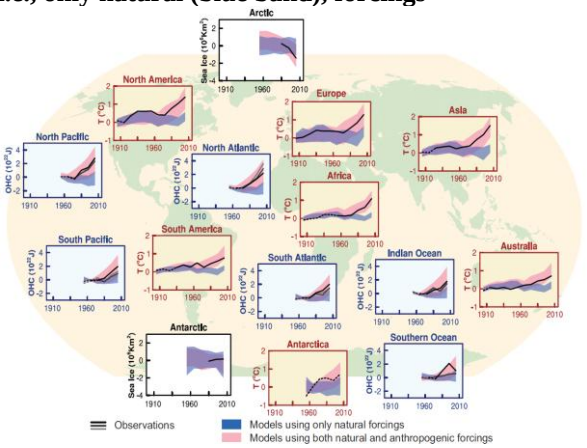
Map of the observed surface temperature change from 1901 to 2012



Source: Summary for policymakers in the contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.1(b).

Figure 12

Comparison of observed and simulated climate change in continental land surface air temperatures (yellow panels), Arctic and Antarctic September sea ice extent (white panels), and upper ocean heat content in the major ocean basins (blue panels) with all forcings (red band) or without anthropogenic, i.e., only natural (blue band), forcings



Source: Summary for policymakers in the contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.6.

20. Mr. Stocker illustrated how Earth system models were used to project changes in the climate system. These models, based on the changes in CO_2 and other drivers, estimate the resulting changes in radiative forcing and temperature, which can be quantified using the transient climate response and equilibrium climate sensitivity. Changes in temperature then create a climate response (e.g. sea level rise) and physical and biogeochemical feedbacks.

21. **Regarding the reliability of the projections** made with climate models, he concluded that, based on a comparison of results from simulations using climate models and observed data, **climate models can reproduce observed surface temperature patterns and trends over many decades not only on the global, but now also on a continental scale** and can therefore be used for projections into the future. He illustrated this with an example of projected changes in average surface temperature and precipitation for 2081–2100 compared to 1986–2005 in the case of the representative concentration pathway (RCP) 2.6 (CO_2 eq concentration reaching 475 ppm by 2100). Changes are much larger for RCP8.5.[8]

22. He also noted **a new quantity** to characterize the climate system, the **transient climate response to cumulative carbon emissions** (TCRE), which is *likely*[9] in the range of 0.8 to 2.5 °C per 1,000 GtC or 3,666 $GtCO_2$.[10] This leads to the important finding that **cumulative emissions of CO_2 will largely determine global**

[8] See box SPM.1 on Representative Concentration Pathways (RCPs) and footnote 17 below.

[9] The same conventions for highlighting uncertainty language using italic fonts as adopted by IPCC AR5 (see AR5 WGI SPM, page 4, notably footnotes 1 and 2).

[10] See further explanations on this matter in paragraph 35 below.

mean surface warming by the late twenty-first century and beyond. WGI assessed that the **cumulative total emissions of CO_2 and global mean surface temperature response are approximately linearly related**. Therefore, cumulative emission amounts enable one to easily make a reasonable estimation of the corresponding future temperature response of the Earth for a given amount of carbon emitted to the atmosphere.[11]

2. General discussion

23. A Party asked whether AR5 WGI has provided **a value for the global average temperature change since 1750**[12]. Responding to this question, the expert answered that, due to absence of a data set, WGI could not estimate the warming for the period since 1750 as reliably as the temperature changes for the period 1880–2012.[13]

24. On the issue of climate models, another Party asked about the **reliability of near-term temperature projections**, considering the reduced rate of warming of the last 15 years. The expert answered that the current generation of climate models can and does simulate reduced warming over several years. However, on the decadal timescale it is difficult to predict the precise time point at which such reduced warming will start. He also said that the increase in global mean temperature for a 15-year period starting in 1996 would be almost three times larger than for the one starting in 1998, which illustrates the sensitivity to the starting year of a trend spanning only such a short period.[14]

25. In response to a question on whether WGI focused on **specific temperature targets** in the course of the assessment, the expert clarified that WGI has not focused on any specific temperature targets or scenarios as the work of the IPCC is policy-relevant but not policy-prescriptive.

26. A Party asked for further clarification of the **relationship between increasing GHG emissions and changes in the climate system, especially in regard to the sea level rise corresponding to a TCRE value of 0.8 to 2.5 °C per 1,000 GtC**. The expert answered that it is difficult to capture the impact of sea level rise that is equivalent to a given TCRE, as the sea level responds in a more complex manner than temperature and more slowly (i.e. much delayed) to changes in the climate system.[15]

27. Responding to a question on whether there were **metrics** to support the review of the adequacy of the long-term global goal considering the time-horizon, the expert answered that no single metric can accurately compare all consequences of different emissions, and that the selection of the metric depends on the policy goals and the time horizon of that policy goal.[16]

28. A Party sought clarification on **uncertainties** and their implication for the policy-making process when a wide range of estimates are provided. For example, by 2050, Earth system models for scenarios compatible with RCP2.6 predict annual CO_2 emissions that are lower than 1990 emissions by 14 to 96 per cent.[17] Regarding this point, the expert advised that despite wide ranges the mean or other best estimate value of the model range can nevertheless often be used, in this case IPCC having estimated it to be 50 per cent. He added that all uncertainties in WGI should in general be treated the same way and on both ends of the range.

[11] For further details, see paragraph 19 of this report and the AR5 WGI summary for policymakers (SPM) , figure SPM.10.

[12] This somewhat arbitrarily chosen year was used by IPCC to define the pre-industrial period, before 1750, and the industrial period as after 1750.

[13] See paragraph 18 above.

[14] See footnote 5 SPM and paragraph 65.

[15] See further explanations on this matter in paragraph 38.

[16] WGI assessed that no single metric can accurately compare all consequences of different emission pathways. For further details on metrics, see chapter 8, section 8.7 for emission metrics.

[17] SPM, page 27.

B. Theme 1: the adequacy of the long-term global goal in the light of the ultimate objective of the Convention based on the contribution of Working Group I to the Fifth Assessment Report

1. Presentations by experts

29. Mr. Detlef van Vuuren (IAMC/PBL), presented benefits and limitations of the RCPs[18] and compared these scenarios with those from the IPCC *Special Report on Emissions Scenarios* (SRES). He provided four reasons to develop new scenarios for climate assessment: (i) to cover a wider range of GHG concentrations, as SRES only includes scenarios without reference to climate policy and thus provides limited insight into twenty-first century warming and warming commitment; (ii) to widen the set of parameters, such as in reference to land use and pollutants, as climate models have become more complex; (iii) to include scenarios that cover both mitigation and adaptation, which requires collaboration between the IPCC working groups; and (iv) to use more recent insight into trends of scenario drivers.

30. He stressed that **RCPs are the cornerstone of the new process of scenario development**,[19] which was **applied in AR5 to shorten the time between the development of emissions scenarios and their use in impact research**, as well as to address the key information needs of users more effectively. He noted that RCPs nicely span the range of GHG emissions from scenarios in the literature. In terms of radiative forcing, RCP8.5 is comparable to SRES A2/A1FI, RCP6.0 to SRES B2/A1B, and RCP4.5 to SRES B1. There are no SRES scenarios that are comparable to RCP2.6.

31. Regarding scenarios corresponding to **RCP2.6**, he noted that the **decarbonization rate should be around 6 per cent per year after 2030, with an average of 4.5 per cent for 2010–2050**.[20] Assuming that global GHG emissions would peak around 2020, such scenarios would nevertheless require negative emissions by the end of the twenty-first century produced by using bioenergy and carbon dioxide capture and storage (BECCS). It would be **possible to delay the peaking time, although only with stronger emission reductions in the period 2030–2050** (e.g. –5 per cent reduction annually) **and with deeper negative emissions**,[21] to remain in line with RCP2.6. Alternatively, some models show that it is **possible** to be in line with RCP2.6 **without negative emissions, but such scenarios would require immediate and more stringent reductions in global emissions**.

32. Mr. van Vuuren concluded that **RCPs have supplied a strong link between the work of WGI and WGIII;**[22] have allowed for **a set of policy-relevant conclusions to be drawn by the WGI and, at the same time, for WGIII to use results from updated models**; this has allowed for a **strong research focus on the feasibility of the 2 °C goal**. He also said that further research is needed on climate impacts based on RCPs, such as in regard to the assessment of socioeconomic conditions.

33. Mr. Stocker summarized the findings of WGI on the **past, current and future changes in the climate system** (e.g. in temperature, precipitation, ocean acidification, cryosphere, and sea level rise). These findings indicate that it **is *likely* that the global surface temperature will exceed 1.5 °C by the end of the twenty-first century relative to the average of the 1850–1900 period for all scenarios except RCP2.6**.[23] Warming will continue beyond 2100 under all RCP scenarios except RCP2.6, will continue to exhibit interannual-to-decadal

[18] RCP8.5: high-range emission scenario (possible development for high population numbers, high fossil/coal use); RCP6.0: medium-range emission scenario (low–medium baseline scenario or high mitigation scenario); RCP4.5: medium-range emission scenario (high mitigation scenario); RCP2.6: low-range mitigation scenario.

[19] See *Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies* published in 2007 at <http://www.ipcc.ch/pdf/supporting-material/expert-meeting-ts-scenarios.pdf>.

[20] See figure on global decarbonization on slide 9 of the presentation by Mr. Van Vuuren, available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2_vvuuren13sed2_amended.pdf>.

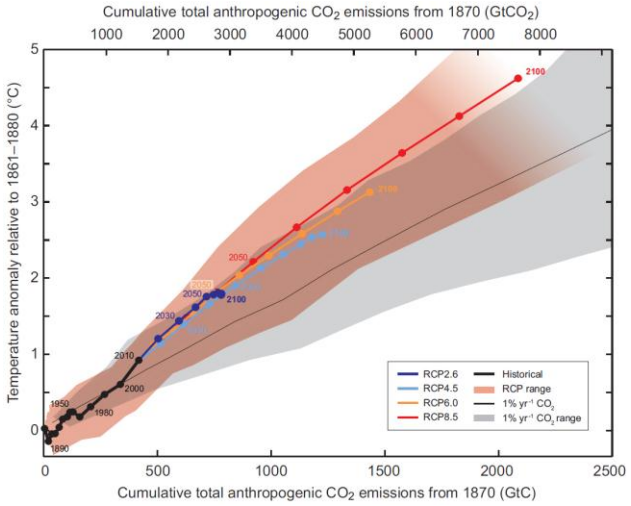
[21] If sustainable bioenergy is able to provide 150 EJ per year, and all bioenergy is used for BECCS, negative emissions of –10 Gt CO_2 per year are possible.

[22] IPCC Working Group III.

[23] See SPM, page 20 and figure SPM.7(a). Note that the temperature increase given in that figure is relative to the reference period 1986–2005, which is estimated to have an average that is 0.61°C above that of the period 1850–1900 (SPM, page 19 and note a to table SPM.2).

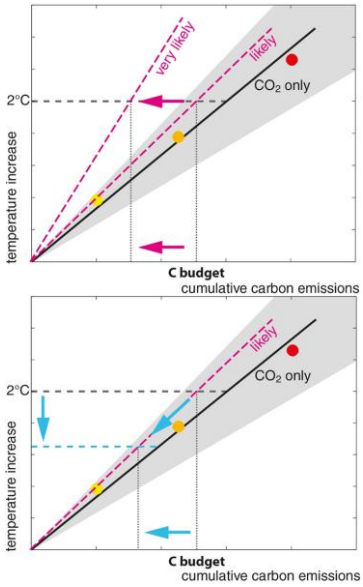
variability and will not be regionally uniform. The Northern Hemisphere sea ice extent in September will decrease for all scenarios and a nearly ice-free Arctic Ocean in September is *likely* before the middle of this century for RCP8.5.

Figure 13
Global mean surface temperature increase as a function of cumulative total anthropogenic emissions of CO_2 from various lines of evidence



Source: Summary for policymakers in the contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.10.
Abbreviation: RCP = representative concentration pathway.

Figure 14
Controls on the carbon budget



Source: Slides 6 and 7 of the presentation by Mr. Reto Knutti (IPCC), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/7_knutti13sed2.pdf>.
Note: The upper figure shows the reduction in the budget with increasing likelihood to keep warming below 2°C, and the lower the reduction in the budget with lowering the temperature target for the same likelihood for keep warming below 2°C.

34. Regarding global mean sea level rise (GMSLR), Mr. Stocker mentioned that for the first time, WGI was able to make a statement encompassing all the important components that contribute to sea level rise.[24] Regarding ocean acidification in the long term (2081–2100), RCP2.6 shows small changes in pH (from –0.06 to –0.07), while RCP8.5 shows a larger change (from –0.30 to –0.32 pH) by the end of the twenty-first century. Regarding extreme events, it is *very likely* that heatwaves will occur with higher frequency and duration; in case of RCP8.5, e.g. warm days[25] will be over six times more frequent by the end of twenty-first century than during the period 1961–1990.

35. He stated that **cumulative total emissions of CO_2 since 1870 and global mean surface temperature response are approximately linearly related** for all RCPs,[26] and that total cumulative CO_2 emissions since 1870 **must be limited to about 1,000 GtC in order to *likely* limit anthropogenic CO_2-induced warming to below 2 °C compared to the period 1861–1880** (figure 13). When accounting for non-CO_2 forcings, this budget is reduced to about 790 GtC; 515 [445–585] GtC have been emitted by 2011.

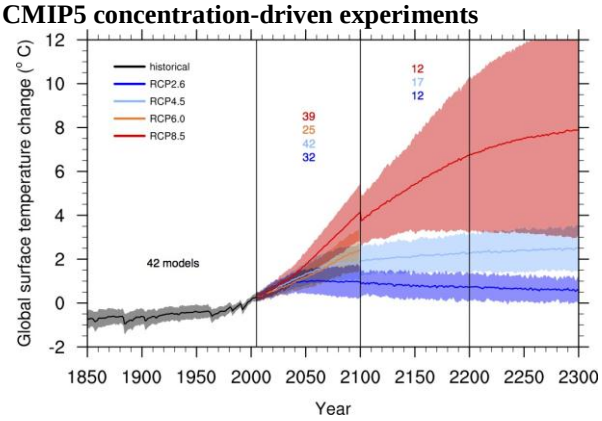
36. Regarding long-term aspects, he explained that global temperature will continue to rise by up to 8 °C beyond 2100 in RCP8.5, and that most aspects of climate change will persist for many centuries even if

[24] See paragraphs 37–41 below for more information.
[25] Frequency of days above the 90th percentile of maximum temperature.
[26] See paragraph 22 above.

emissions were stopped at this moment (figure 15). He concluded that these results represent the **substantial multi-century climate change commitment created by past, present and future emissions of CO_2.**

Figure 15

Time series of global annual mean surface air temperature anomalies (relative to 1986–2005) from CMIP5 concentration-driven experiments

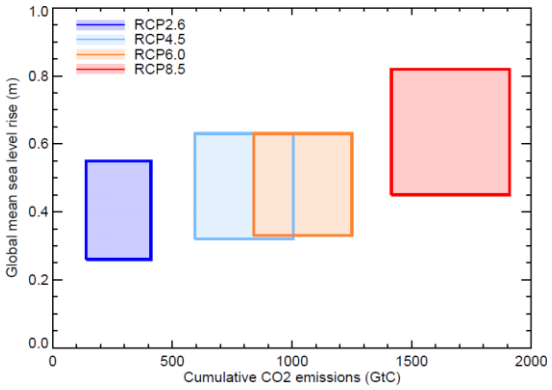


Source: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure 12.5.

Abbreviations: CMIP5 = Coupled Model Intercomparison Project Phase 5, RCP = representative concentration pathway.

Figure 16

Relationship between GMSLR, RCPs, and cumulative CO_2 emissions



Source: Slide 9 in the presentation by Mr. Jonathan Gregory (IPCC), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/4_gregory13sed2.pdf>

Note: See also the summary for policymakers in the contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, table SPM.2.

Abbreviations: GMSLR = global mean sea level rise, RCP = representative concentration pathway.

37. Mr. Jonathan Gregory (IPCC) presented findings of WGI on GMSLR. He explained that GMSLR is a result of an increase in the volume of the global ocean as caused by the warming of the ocean (thermal expansion),[27] ice loss from glaciers[28] and ice sheets,[29] and the change of liquid water storage on land (groundwater and reservoirs). For example, the global glacier volume is projected to decrease by 15 to 55 per cent for RCP2.6, and by 35 to 85 per cent for RCP8.5 by the end of the twenty-first century. Regarding observed changes, the rate of GMSLR from 1901 to 1990 was 1.5 [1.3–1.7] mm per year, and 3.2 [2.8 to 3.6] mm per year from 1993 to 2010.

38. It is *very likely* that the average rate of the sea level rise during the twenty-first century will exceed that of the period 1971–2010 under all RCPs. A GMSLR of 0.40 [0.26–0.55] m for RCP2.6 and 0.63 [0.45–0.82] m for RCP8.5 was projected for the period 2081–2100 compared to 1986–2005 (*medium confidence*), and of 0.28−0.61 m for RCP2.6 and 0.52−0.98 m for RCP8.5 by 2100. The collapse of marine-based sectors of the Antarctic ice sheet, if initiated, would add no more than several tenths of a meter during the twenty-first century (*medium confidence*). **Unlike global mean surface warming, the rate of GMSLR depends also on the pathway of CO_2 emissions, not only the total amount of CO_2 emitted, which means reducing emissions earlier rather than later will lead to a lower sea level rise** (figure 16).

39. Commitment to and irreversibility of sea level rise are important aspects, as **stabilizing the global mean surface temperature (**e.g. towards the end of this or during the next century) **will not stabilize the global mean sea level**.[30] It is virtually certain that GMSLR will continue for many centuries beyond 2100. Depending on

[27] *High confidence* in projections of thermal expansion and consistency of historical simulations with observations.

[28] *Medium confidence* in projections of glacier mass loss and consistency of historical simulations with observations.

[29] *High confidence* in projections of increasing Greenland surface mass loss and *medium confidence* in projections of increasing Antarctic snow accumulation.

[30] For example, while global surface temperature stabilizes between 2081 and 2100 for RCP2.6, GMSLR continues then still at a rate of 2–7 mm per year.

future emissions, it could eventually reach several meters above pre-industrial levels and possibly include irreversible ice sheet mass loss.

40. **Regarding the projection for 2300**, there is *medium confidence* for a GMSLR lower than 1 m for radiative forcing corresponding to CO_2 concentrations below 500 ppm (about 3 W m^{-2}, similar to RCP2.6), and from 1 to more than 3 m for CO_2 at 700–1,500 ppm (about 5–9 W m^{-2}, as in RCP6.0 or RCP8.5). Sustained warming greater than a certain threshold above the pre-industrial level would lead to a near-complete loss of the Greenland ice sheet (*high confidence*). **That threshold for global mean warming is assessed to be greater than 1 °C** (*low confidence*) **but lower than 4 °C** (*medium confidence*) **with respect to pre-industrial levels**.

41. **Regarding regional changes** by the end of the twenty-first century, Mr. Gregory underlined that it is *very likely* that sea level will rise in more than about 95 per cent of the ocean area and that there will be a significant increase in the occurrence of extreme high sea level events. **About 70 per cent of the coastlines worldwide are projected to experience sea level change within 20 per cent of the global mean sea level change**.

42. Mr. Krishna Kumar Kanikicharla (IPCC) presented **regional changes** and their deviations from global means.[31] He explained that the IPCC was able to use more data sets for AR5 than for AR4,[32] which resulted in more precise data at the regional level, including changes in observed surface temperature and precipitation. He illustrated projected changes in temperature and precipitation for the period 2081–2100, which vary from region to region with various confidence levels. He stressed the **correlation between annual precipitation and changes in extreme events** (maximum five-day precipitation and consecutive dry days for 2081–2100 and RCP8.5), highlighting differences between regions in Latin America and Asia.

43. Mr. Kumar showed how features of regional climate change have been identified and assessed in AR5 WGI through important climate phenomena such as monsoons, El Niño/Southern Oscillation (ENSO) and tropical cyclones and noted that the report provides an Atlas of global and regional climate projections (temperature and precipitation for 3 time horizons and all RCPs) for 35 regions and based on results from 42 global models.

2. General discussion

44. During the **group discussion**, representatives of the European Union, New Zealand, South Arica and AOSIS asked questions and commented on the presentations. In response to a question regarding developments in the **current research on the threshold for critical and significant impacts in the climate system**, in particular regarding what types of **tipping points we should be aware of in order to assess the adequacy of the 2 °C limit**, an expert answered that the findings on the irreversibility of ice sheet mass loss and the time series of ocean acidification have improved.[33,34] Regarding the **predictability of critical thresholds**, another expert said that there has been some progress in identifying these points or whether such points exist for specific components, such as the Greenland ice sheet mass loss or ocean acidification.[35]

45. In response to a question on **scenario development**, in particular regarding consideration of scenarios that were published after 2007, an expert answered that some scenarios published by 2011 were considered in the process of updating and developing RCPs, while scenarios that were developed after 2012 have been considered by WGIII.

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[31] See chapters 2, 12, 14 and annex I of WGI for regional information.

[32] Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

[33] See paragraphs 34–41 above for details on sea level rise and AR5 WGI, chapter 12, section 12.5, for irreversible changes, chapter 13 for irreversibility of ice sheets and sea level rise.

[34] Impacts to marine ecosystems due to the ocean acidification will be mentioned in the contribution of Working Group II to the Fifth Assessment Report of the IPCC.

[35] For some components critical thresholds are clear from the nature of the process (e.g. melting point of ice in case of the melting of ice sheets, and transition to undersaturation in the case of ocean acidification). See also AR5 WGI Thematic Focus Element TFE.8 on "Climate Targets and Stabilization" in the Technical Summary, notably page 105.

46. A question arose on the **improvement of models for regional precipitation**. The expert answered that models have been improved in this area, for example by increasing their spatial resolution and by improving how they report projections (e.g. hatching patterns show the multi-model mean is small compared to natural internal variability and stippling patterns show that the multi-model mean is large compared to natural internal variability and that at least 90% of the models agree on the sign of change).

47. In response to a question regarding possible limitations due to **working only with a temperature related goal,** an expert explained that such a goal **might not capture all impacts that follow from emissions** and may thus cause other changes in the climate system to be overlooked. For example, the sea level rise beyond 2100 is not scalable with cumulative carbon emissions and leads to a centuries-long commitment, which means that additional measures or stringent limitations on cumulative carbon emissions are necessary to prevent such impacts.[36] He added that meeting **multiple goals would require a more ambitious effort to reduce emissions**.

48. With regard to costs, a Party commented that for Africa, a 1 °C warmer world seems to imply costs within the realm of a 0 °C increase; whereas a 2 °C increase implies costs significantly higher than for a 1 °C increase; and a 3 °C increase is associated with a drastic shift in climate impact and adaptation-related costs, as exceeding critical thresholds results in high-impact climate events.

49. During the **general discussion**, several Parties requested clarification on **underlying assumptions for RCP2.6**[37] and on the consideration of **emissions of short-lived gases**, such as fluorinated gases, particularly hydrofluorocarbons (HFCs). An expert noted that these questions are related to the work of WGIII and elaborated on the technical feasibility[38] and cost estimates for RCP2.6.[39] Another expert said that WGIII is assessing the economic cost, as well as the social and environmental aspects, technology development, and energy profile trajectories. Yet another expert encouraged delegates to participate in the review process of WGII[40] and WGIII draft reports, as many questions were related to those two reports. In reference to the second question, an expert answered that HFCs are also considered in these scenarios.[41]

50. Two questions arose **regarding the 1.5 °C target**: (1) what are the **regional implications of the difference between impacts caused by temperature increases of 1.5 °C and 2 °C**; and (2) which chapters of AR5 WGI present information on impacts from a 1.5 °C increase. Responding to the first question, an expert answered that WGI compared global and regional changes by RCPs rather than in terms of a 1.5 °C versus 2 °C increase. He then said that the projected regional near-term impacts for RCP2.6 may be closest to impacts that could be associated with a 1.5 °C temperature rise. For the second question, the expert answered that the relevant information for the 1.5 °C increase can be found in chapter 11 (near-term projections), chapter 12 (long-term projections), chapter 13 (sea level rise), and chapter 14 (regional issues), as well as in contributions of WGII, WGIII and the Synthesis Report.

51. A Party asked for further clarification on the issue of **multiple goals**, referred in paragraph 47 above, in particular regarding a temperature related goal combined with an ocean acidification or sea level rise goal. The expert answered that, although the issue of multiple goals is relatively new to the scientific community, AR5 WGI provides information for each scenario on the degree of ocean acidification and sea level rise, which also covers relevant temperature related goals that UNFCCC is currently considering. Regarding the sea level rise, another expert reiterated that, in general terms, reducing emissions earlier rather than later would lead to a lower sea level rise.

[36] See paragraphs 39 and 40 above.

[37] For example, social and economic aspects such as technical feasibility, cost implications and discount rate, economic growth in developing and developed countries and barriers to technology transfer.

[38] Some models show pathways that are feasible without negative emissions but require immediate emission reductions. Options to reach negative emissions include BECCS, forestation and direct air capture. BECCS seems like a promising option compared to forestation, but requires a trade-off with food production.

[39] For example, costs are about 2 per cent of GDP, a discount rate of 5 per cent is used, and a higher growth rate is used for developing countries than for developed countries.

[40] Working Group II of the Intergovernmental Panel on Climate Change.

[41] See details in annex II of AR5 WGI.

52. In response to a question on **extreme events in mid-latitude regions**, an expert explained the existing complexity of and difficulties in making projections for such extreme events, including wildfire,[42] tornadoes, tropical storms and cyclones.

53. Another Party underlined the importance of **adaptation costs** in policymaking in the context of the long-term global goal. Yet another Party mentioned a paper that analysed the attribution of climate change to human activities using statistical methods rather than models.

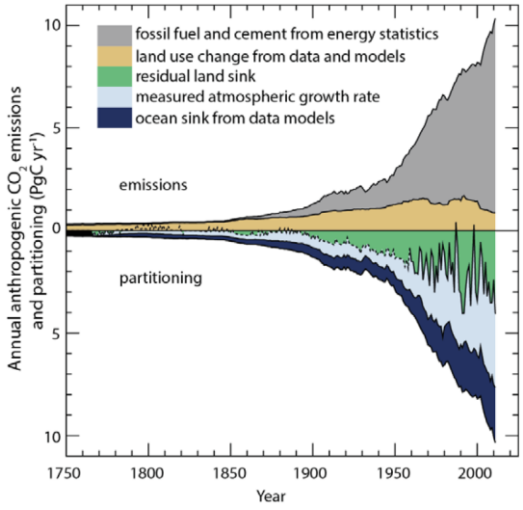
C. Theme 2: overall progress made towards achieving the long-term global goal, including a consideration of the implementation of the commitments under the Convention

1. Presentations by experts on trends in global greenhouse gas emissions and concentrations

54. The **first part of theme 2** focused on global GHG emissions and concentrations. Ms. Corinne Le Quéré (IPCC) presented past, current and projected changes of global GHG emissions and concentrations. In 2011, the concentrations of GHGs in the atmosphere reached 390.5 ppm for CO_2 (40 per cent increase compared to the pre-industrial period); 1,803 ppb for methane (CH_4) (150 per cent increase) and 324.2 ppb for N_2O (20 per cent increase). WGI concluded that **the largest contribution to total radiative forcing is caused by the increase in atmospheric CO_2**.

Figure 17

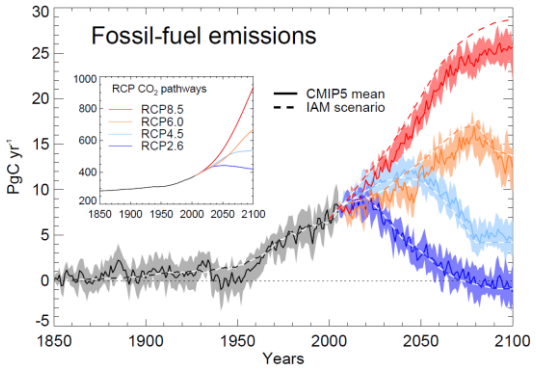
Annual anthropogenic CO_2 emissions and their partitioning among the atmosphere, land and ocean from 1750 to 2011



Source: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change , Technical Summary, figure TS.4

Figure 18

Compatible fossil fuel emissions simulated by the CMIP5 ESM models for the 4 RCP scenarios



Source: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure 6.25.

Abbreviations: CMIP5 = Coupled Model Intercomparison Project Phase 5, ESM = Earth System Model, IAM = Integrated Assessment Modeling, RCP = representative concentration pathway.

55. Regarding historical emissions from 1750 to 2011, **CO_2 emissions from fossil fuel combustion and cement production** have released 375 [345–405] GtC into the atmosphere (some 70 per cent of total cumulative emissions), while deforestation and other land-use change are estimated to have released 180 [100–260] GtC (some 30 per cent of total cumulative emissions).[43] Some 155 [125–185] GtC have been taken up by the ocean

[42] Projection of wildfire or heatwaves need projections of the quantity of soil moisture, but the global models used for the former have not captured the latter.

[43] Land-use change emissions are subject to large uncertainties and can be negative.

and 160 [70–250] GtC have accumulated in residual land sinks (figure 17). **Recently**, over the period 2002 to 2011, **emissions from fossil fuel combustion and cement production amounted to 90 per cent of total CO_2 emissions** while the remaining 10 per cent during that period were due to land-use change.

56. She explained that Earth system models[44] showed that land and ocean CO_2 sinks continue to increase when the models simulated increasing atmospheric CO_2 only, while the opposite response was observed when the models simulated climate change only. The latter showed that **climate change affects the carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere** (*high confidence*).

57. After presenting the cumulative emissions for all RCP scenarios from 2012 to 2100, Ms. Le Quéré said that future emissions following RCP2.6 are on average 50 [14–96] per cent lower by 2050 than 1990 emissions (figure 18), and about half the models indicate emissions below zero by 2100. The **cumulative future CO_2 emissions that are compatible with RCP2.6** (270 [140–410] GtC from 2012 to 2100) **are less than half the historical emissions** (555 [470–640] GtC from 1750 to 2011).

58. Mr. Reto Knutti (IPCC) presented the relationship between global CO_2 emissions and the global temperature rise. He stressed that a substantial multi-century climate change commitment was created by past, present and future emissions of CO_2. **Stable CO_2 concentration will result in further warming over centuries, and even if CO_2 emissions reach zero,** about **15–40 per cent of the emitted carbon will remain in the atmosphere for longer than 1,000 years** depending on the scenario. However, most models show no or very little commitment to further surface warming from past CO_2 emissions once emissions should stop or become negative.

59. He further stated that cumulative emissions of CO_2 will largely determine global mean surface warming by the late twenty-first century and beyond. WGI found that warming is largely independent of the emission pathway and that only the total amount emitted matters. Hence, every ton of CO_2 causes about the same amount of warming, no matter when and where it is emitted. Therefore, **any temperature limit implies a maximum amount of cumulative CO_2 emissions compatible with that limit**. **Halting the global mean temperature rise at any level will require near zero carbon emissions at some point in the future**.

60. The total cumulative carbon budget (CO_2 only) corresponding to the likelihood of 90, 66, 50, 33 and 10 per cent of the temperature increase since 1861–1880 staying under 2 °C are 730, 1,000, 1,212, 1,567 and 3,567 GtC, respectively[45]. In the case of a 1.5 °C increase, this budget is estimated at 548, 750, 909, 1,176, and 2,675 GtC, respectively (figure 14). Consideration of non-CO_2 forcing implies a lower budget. For example, the **upper amount is reduced from 1,000 GtC to about 790 GtC when accounting for non-CO_2 forcing as in RCP2.6** (probability greater than 66 per cent of staying under 2 °C); 515 GtC have already been emitted from this budget by 2011. He said **the long-term global goal could be seen as a threshold that must not be exceeded or as an eventual target after overshooting** and noted that some temperature related goals are very difficult to reach if defined as a threshold, but can be reached eventually after overshooting.

2. General discussion

61. During the **group discussion**, Brazil, China, the European Union and Switzerland asked questions and commented on the presentations. Some questions arose on **emissions from fossil fuels and land-use change**, including on their geographic distribution, the means to secure land sinks so as to continue the absorption of carbon, and the **relationship between emissions and the capacity of land and ocean sinks**. The experts explained that there is solid data for the geographical distribution of emissions from fossil fuel, but that for land use there was no agreement among experts regarding the distribution by region, even for recent decades. They also explained that, if sink capacity is to be secured, deforestation and changes in the climate should be limited. There is a relatively linear trend between emissions and the response of land and ocean sinks except for cases of higher emissions. The experts further said that, **while the quantification of changes in land and ocean sinks for high emission scenarios is difficult, the direction is clear: such scenarios will weaken the capacity of sinks**.

[44] Climate models that take into account carbon cycle processes. This includes uncertainties in carbon climate feedbacks, except feedbacks from frozen permafrost, from wetlands with a warmer climate and from marine hydrates.

[45] All numbers given here are estimates derived using the same method as described in AR5 WGI, Chapter 12, page 1113.

62. A Party asked about the **relationship between emissions and impacts such as ocean acidification, sea level rise or food production**. The experts answered that this relationship is not linear, and that different goals may require different carbon budgets. He also explained that a goal linked to food production may require the assessment of additional components that go beyond physical changes in the climate system.

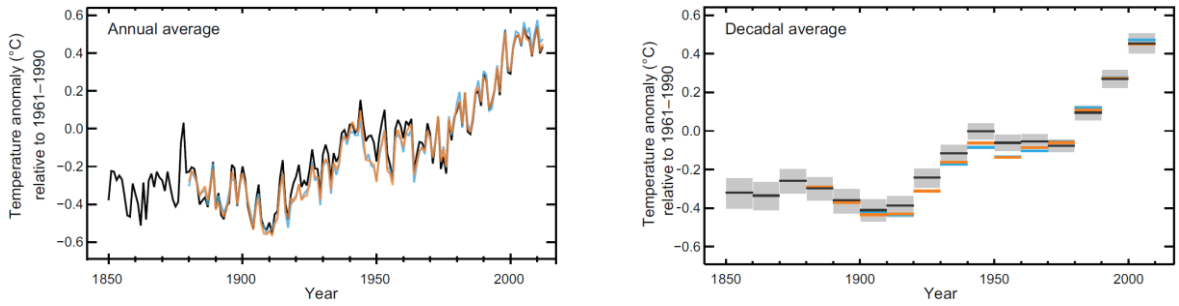
63. Responding to Mr. Knutti's presentation, a Party pointed out the importance of the **emission pathway and the rate of changes in the climate system**, as different pathways may show different types and rates of impacts. Therefore, an important message is that **global emissions have to peak and decline in the near future to reach a low-emission pathway and limit warming**. The expert responded that the rate of climate change and the exact emission pathway, in contrast to global mean temperature, may indeed matter for some impacts such as sea level rise.[46]

64. A Party asked a question about the **uncertainty ranges** and how they would impact policymaking, in particular in regard to the fact that such ranges translate into differences in future budgets equivalent to historical cumulative emissions. The Party noted that the practical meaning of such ranges is important and that further efforts are needed to reduce the uncertainties.[47] A different Party asked about the uncertainty range associated with the 50 per cent reduction by 2050 required by RCP2.6. He noted that the uncertainty comes in at different timescale, for example for concentrations and temperatures, and there is much less uncertainty for concentrations than for temperature profiles in going forward. It stressed that **uncertainty should be considered in risk management and that higher uncertainties will mean a lower carbon budget**, for example. The expert answered that the range of values represents the minimum to maximum values provided by all the models and that it is not very large if standard deviation is considered. He reiterated the need to focus on the total budget rather than total emissions at a given point in time, agreed that higher uncertainties will mean a lower carbon budget[48] and noted that the question of choosing a specific probability of keeping temperature below a given limit is not a scientific question nor a scientific uncertainty but is to be addressed as part of a value judgment.

65. Another Party was of the view that the **progress towards the long-term global goal** should be assessed **in terms of temperature**. He suggested that the goal should be broken down into partial targets that would be assessed every 10 years,[49] and asked about the feasibility of developing a methodology for this purpose. In response, an expert noted that adopting such an approach would be difficult, owing to the difficulties associated with the decadal predictability of temperatures. He stressed that there are periods with less warming (figure 19), and that short-term trends could lead to wrong conclusions when compared with long-term trends.[50] Instead, he pointed out, the goal should be revised based on emissions, which are well documented and for which we have a clear understanding of what they mean in terms of long-term commitments.

Figure 19

Observed global mean combined land and ocean surface temperature from 1850 to 2012, from three data sets



Source: Summary for policymakers in the contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.1(a).

[46] See figure 58 and 61 above.

[47] See paragraph 28 above.

[48] See figure 58 and 59 above.

[49] The scientific community would assess the temperature targets, while policymakers would assess mitigation actions that combat temperature increases.

[50] See paragraph 24 above.

66. During the **general discussion**, a Party asked about the assessment of **risk of carbon cycle feedbacks** associated with different degrees of warming, especially **regarding whether overshooting scenarios would increase the risk of these feedbacks**; about which is a safer global warming limit for reducing these risks (1.5 °C or 2 °C); and about whether high probability emission pathways to limit warming to 1.5 °C would reduce the risk of overshoots and carbon cycle feedbacks. An expert answered that higher emission scenarios have broader feedbacks. She also mentioned that keeping the temperature rise below 1.5 °C could also help control carbon cycle feedbacks, and that smaller temperature changes will lead to smaller feedbacks.

67. A different Party asked two questions regarding the **relationship between the timescale and impacts**: (1) at what point do the impacts of a 2 °C rise matter; (2) is the timescale the same for various physical changes in the climate system, such as precipitation, ocean acidification or sea level rise? An expert answered the first question by saying that the timescale of the impacts will depend on the type of impacts. For example, warming will immediately impact precipitation or extreme weather, whereas changes in the Greenland ice sheet melting would take considerably much longer to occur and a few years would not matter.[51] In general, the timescales for emitting carbon might also apply to those for taking carbon out of the atmosphere (e.g., if we overshoot for 50 years we might stay above the target for 50 years).

68. In response to the second question, the expert said that there is no linear feedback in the case of ocean acidification, as the upper and deeper ocean have different acidification profiles. Regarding changes in extreme events in terms of early versus late reduction, the expert answered that both global and local temperature matter for extreme events, and that thus the timing of reductions does not affect the timing of the events. Regarding the relationship between timescale and impacts he said that the reduction of emissions short-lived GHGs will show an effect immediately (e.g., the effect of reducing emissions of a short lived GHG in 2050 is seen in 2050 not in 2100). However, another expert added that reductions of short-lived GHGs emissions ought to be seen in addition to those of long-lived GHGs (particularly CO_2) to effectively manage a long-term goal.

69. Regarding a question on a **committed temperature rise** for RCP2.6, an expert answered that the temperature rise that is projected under RCP2.6 is *likely* below 2 °C in 2100 relative to the 1850 level (the mean response of models is about 1.6 °C). As regards commitments, he said that there is no warming commitment from past emissions in the physical climate system[52] that will cause further warming and that if we stop emissions today entirely, there will be no further warming. Essentially, the commitment to future warming is in future emissions. A stable concentration, however, will result in further warming.

70. Another Party asked whether there is coordination between WGI and WGII on reflecting the impact of a committed temperature rise on the cost of adaptation, which will be assessed by WGII. The expert answered that impacts and adaptation will be discussed in the WGII report for the same scenarios using the projections from the climate models from AR5 WGI.

71. Responding to a question regarding the **recent increase of CH_4 emissions from natural wetlands**, an expert said that while natural variability has caused a slowdown in recent warming, there are limited data available to support attributing the increase in CH_4 to a particular process. Only the results from one model linked this increase to changes in rainfall (not a systematic change) and to changes in fossil fuel emissions.

72. With regard to the **commitment from carbon infrastructure** that has already been built, an expert explained that this matter is addressed mainly by WGIII and that the question is if that infrastructure will be phased out at the end of its lifecycle or earlier.

73. In response to a question regarding the **potential of land sinks** in RCPs by 2050, an expert explained that the RCPs have clear pre-defined emission pathways for the twenty-first century. On the other hand, in the context of the discussion on uncertainty, the earth system models used by WGI show changes in sources of terrestrial biosphere sinks based on assumptions about vegetation and the climate change, in particular in precipitation.

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[51] According to IPCC AR5 a global warming higher than a certain threshold value above preindustrial levels sustained over a millennium or more would lead to the near-complete loss of the Greenland ice sheet, causing a global mean sea level rise of up to 7 m. See AR5 WGI SPM page 29 and Executive Summary of chapter 13.

[52] Which is only true for global mean temperature but not for other responses of the climate system such as sea level rise. See also paragraphs 39, 58 and 63 above.

3. Presentations by experts on lessons learned from support in technology, finance and capacity-building

74. **Second part of theme 2** focused on lessons learned from support in technology, finance and capacity-building. Mr. Antonio Pflüger, the Chair of the TEC, outlined the **key milestones in the technology process under the Convention**, culminating with the establishment in 2010 of the Technology Mechanism comprising the TEC, which provides policy recommendations and briefs to the COP and to stakeholders, and the CTCN, which aims to enhance the effectiveness of support for delivering mitigation and adaptation action and responds to developing country Parties' requests. An important component of the technology transfer framework is the technology needs assessments (TNAs), a country-driven process aiming to identify priorities for mitigation and adaptation technologies. The second generation of TNA reports[53] provides information on prioritized sectors and technologies, barriers to and enablers for technology development and transfer, technology action plans, project ideas, estimated budgets for the short and the long term and possible linkages with other processes under the Convention, such as nationally appropriate mitigation actions (NAMAs) and national allocation plans (NAPs). However, the issue of measuring and monitoring the effectiveness of technology development and transfer may need to be further considered.

75. The TEC produced two briefs related to TNAs in 2013 that summarized the **lessons learned from TNAs**,[54] including the following: TNAs are rich sources of information on the technology needs of developing countries; financial and economic barriers are critical and they should be referred to by all financial entities under and outside the Convention; high-level governmental support and coordination of the TNA process is essential; TNAs should evaluate prioritized technologies that may be considered in NAPs and NAMAs; Parties, when preparing NAMAs and NAPs, should ensure coherence with the TNA findings; and the TNA process effectively helps Parties and relevant stakeholders to implement mitigation and adaptation projects.

76. Ms. Diann Black-Layne, the Chair of the SCF, introduced the general mandates of the **SCF** and provided **information relevant to the review**. She said that the questions are how much funding has been provided to place us on track for a 2 °C world and if this support can be further strengthened to meet a more ambitious target. In response to the first question, she said that the amount of funds being currently allocated to climate finance is inadequate to meet the 2 °C target and that some projections indicate that the current level of spending on "brown" technologies will continue to grow faster than that on renewable technologies.

77. Regarding the second question, she stressed that the **SCF will** be in a position to **assess the overall global financial needs for meeting the goals** agreed upon by the Convention and can present this information at a future SED meeting, in 2015 or beyond. Regarding adaptation, she emphasized that although spending on adaptation has increased, the current focus remains on mitigation despite efforts to place more weight on adaptation.

78. Mr. Robert Dixon (GEF) outlined the role of the **GEF** in financing clean energy and technology investments, adaptation and enabling activities. In terms of **lessons learned**, he highlighted the importance of **mainstreaming private sector engagement** in climate financing, **market transformation** through risk reduction in capital-intensive investing, more efforts to enhance **enabling environments** through capacity-building and technical assistance; and strengthening efforts to build the necessary **support infrastructure and policy frameworks** to further scale-up technology investment and archive transformational impact. He also stressed that **capacity-building** activities should be integrated with adaptation efforts, not be stand-alone activities.

79. In the future, the GEF will continue to invest in financing mechanisms and incentives to bring in the private sector; developing local know-how and intellectual capital through technical assistance and capacity-building; supporting countries in their transition to long-term adaptation, in addition to continuing support for urgent and immediate adaptation needs; encouraging a more strategic approach to multifocal area projects and programmes; and accelerating the demonstration and deployment of innovative adaptation and mitigation technologies and associated business models.

[53] See the third synthesis report on technology needs identified by Parties not included in Annex I to the Convention at <http://unfccc.int/resource/docs/2013/sbsta/eng/inf07.pdf>.

[54] Available at <http://unfccc.int/ttclear/pages/tec_home.html>.

4. Discussions (part two)

80. During the **group discussion**, representatives of AOSIS, Mexico and Philippines asked questions and provided comments. **On technology**, their questions included whether technology transfer is shifting the industrial or technology infrastructure in developing countries towards low emission pathways, how the CTCN would evaluate the technology process of the last 20 years, what the timeline for moving from planning technology transfer to starting to measure its achievements and impacts is, and when we will know the technology needs for supporting mitigation and adaptation action.

81. A Party commented that WGI findings are clearly assuming that increased funding, technology transfer and capacity development are required to meet the 2 °C or 1.5 °C goal. On the subject of low-hanging fruit, another Party was of the view that delaying action locks in the high carbon infrastructure, and that it will be more difficult to reduce emissions in the future.

82. Responding to these questions, the TEC expert said that the evaluation of the technology transfer process over the last 20 year should be seen in the light of the mandates provided by the technology transfer frameworks that were developed during that time. He underlined that in the past two years **the technology mechanism has undergone a fundamental change** and is now moving fast, but that more work is needed to make it fully operational. A key message from the TEC is that factors other than funding are equally important for a successful transfer of technologies, including identifying the right partners in the recipient country, establishing good national coordination between institutions working on TNAs, NAMAs, and NAPs, and having an adequate research and development programme.

83. The CTCN expert responded that the technology mechanism created by Parties captures the full spectrum of technology transfer, diffusion and adoption. The CTCN, hosted by the United Nations Environment Programme (UNEP), will be fully operational soon and will start receiving requests from Parties through their national designated entities.[55] It will identify, based on TNAs, barriers to technology transfer and provide guidance on how to mitigate them. The impact of projects depends on how the recipients of the information and the technology system will implement the recommendations from the CTCN, including on changing policies and regulatory structures and on developing the capacity and skills needed. The CTCN will ask developing countries receiving assistance for feedback on its services and will adjust its activities accordingly.

84. The **questions on climate finance** included how climate finance needs compare to what has been provided,[56] if there is scope for expansion and possible improvement of the effectiveness of the Adaptation Fund and application of its best practices to the work of the Green Climate Fund and the TEC, when SCF will know the financial needs for the period ending in 2050 by sector and region and how these needs will be structured and communicated, and what the rate of co-investment is that will catalyse funding of climate projects and will keep the right appetite for risk.

85. A Party commented that funding for adaptation will be significantly lower for meeting the 1.5 °C rather than the 2 °C goal. Another Party was of the view that SCF should work on the long-term finance pathways needed to achieve the long-term global goal and the modalities for achieving this. Yet other Parties were of the view that the Adaptation Fund should be seen as the benchmark for adaptation finance, because it provides access to finance to national and regional implementation entities and that most support schemes worked when cross-cutting issues were considered (e.g. technical, economic and market potential).

86. Regarding the **support schemes that worked**, an expert gave an example of an oil-importing agreement with Caribbean States that allowed for partial payment combined with a loan at favourable rates, with the condition that the savings generated are invested in poverty eradication and renewable energy programmes. She said that extreme weather events and market signals generated by the price of oil should be the main drivers for climate finance and technology, but that markets failed to react to these drivers. Therefore, the new agreement

[55] Some 30 countries identified such entities.

[56] In the context of this question, a Party provided information on the amount of climate finance required from various sources, as well as on finance provided, as reported in the fifth national communications of Parties included in Annex I to the Convention. Another Party recalled that the commitment made by developing countries to mobilize short-term finance was not reported in those national communications.

should look at the market failures in each country and try to address them. The SCF should have also a role in this.

87. She also suggested that the CTCN should develop **a registry of proven technologies** and thus contribute to reducing the risk inherent in investing in climate technologies. She also said that the Adaptation Fund, which receives funding through the carbon market, will eventually dry up due to market failures. However, the Fund has proven to be one of the most efficient funds because the transaction costs were reduced by providing direct access to funds.

88. During the **general discussion**, a Party underlined that in some countries domestic carbon emissions are at their lowest level in two decades despite economic growth and noted that the UNEP Emissions Gap Report also showed **signs of a beginning of the decoupling of emissions from economic growth**. He talked about international efforts made outside the UNFCCC process to reduce emissions, including by reducing international financing for coal plans and cutting fossil fuel subsidies. Responding to this comment, the GEF expert noted that supporting fuel switching is one of the priorities of the GEF action plan.

89. Another Party underlined that it is making tremendous efforts to support mitigation action domestically and internationally, announced that they surpassed their pledged funding for fast-start finance, and that it is committed on scaling up the mobilization of climate finance in the context of meaningful mitigation action and transparency of implementation. Its GHG emissions in 2011 were reduced by 18 per cent compared to 1990, while the region's gross domestic product grew by 45 per cent in the same period.

90. Yet another Party commented that many developing countries have undertaken TNAs but that the technology transfer is not happening. Responding to this comment, the TEC expert said that countries need to follow up and implement the institutional, policy, regulatory and technology road map identified in TNAs. The TEC and the CTCN were created to support the countries' efforts on this matter.

91. Regarding a question on providing an example of when **intellectual property rights** prevented technology transfer and how this will be addressed, the TEC expert answered that this matter should not be addressed in the UNFCCC process but under the auspices of the World Trade Organization as part of trade-related aspects of intellectual property rights. He said that, in general, intellectual property rights facilitate and catalyse, not inhibit, the development of technologies. He also added that developing countries identified in their TNAs the lack of finance, policy and regulatory structures, as well as gaps in knowledge and human capacities, as key barriers to technology transfer. Intellectual property rights were not among these five key barriers, he added, and it is unfortunate that this issue has become a distraction from accelerating technology transfer. This point was echoed by the GEF expert.

92. One Party asked about the **role of the private sector in investing in adaptation**, from a business risk perspective, and about how Parties could **better engage subnational actors** to scale up action on mitigation and increase resilience, particularly in the pre-2020 period. The TEC expert answered that there is a trend of decentralization of the economic and political power to the subnational level, increasing the importance and role of subnational level actors as they become responsible for mitigation and adaptation projects. He also noted the importance of integrating national programmes with action by states and cities. For example, he noted that there are many corporations looking at making cities more resilient to climate change. He also talked about spatial integration as an additional dimension to sectoral integration and about improving vertical communications from local to city, state and national levels. The GEF expert noted that working with cities and local governments had been successful in the past, that the GEF would like to build on this good experience in the future and that mainstreaming adaptation in national planning was an important step forward.

93. Regarding a question on how the GEF has managed to implement a large number of projects at USD 1/tonne CO_2, the expert responded that the GEF has indeed financed many cost-effective clean energy and technology investments, which is part of GEF's role and design.

94. Regarding the question on **leveraging private sector investment** and the existence of **guidelines on the bankability of mitigation and adaptation projects**, the GEF expert said that such resources exist. He provided an example regarding the concentrating of solar power, where the GEF took on higher risks 15 years ago by investing in big technology projects in developing countries, and noted that this made possible the implementation of those projects, which are now in operation. In general, the GEF is looking at technologies that are at the end of the research and development pipeline and might be attractive in the future, such as smart grids,

fuel switching and carbon dioxide capture and storage, as well as at new financial instruments and investments that integrate multiple benefits.

95. In response to a question, the SCF expert explained some of the **difficulties in defining what constitutes new and additional financing**, including in defining what a low-carbon technology is and what sort of role the TEC and the CTCN may play in the future in this matter, in deciding whether or not to count in this category those funds that are leveraged by a project, as well as in estimating the flows of funds countries may encounter delay or hurdles in receiving disbursed funds.

D. Reflections on second meeting of the structured expert dialogue

96. It is our perception that the discussions in Warsaw were very productive and informative and that they supported Parties in internalizing the key findings of AR5 WGI relevant to both themes of the review. SED 2 saw you engaging in a constructive and productive manner in all discussions with the IPCC and other experts.

97. Parties had a rich exchange of views with experts on the adequacy of the long-term global goal and the overall progress made so far towards achieving the long-term global goal, including the likelihood of meeting and maintaining the goal, on the basis of AR5 WGI. They also heard from experts some of the lessons learned on the effectiveness of technology and finance support. We congratulate you and the experts on this successful meeting and encourage you to maintain this positive spirit.

98. The presentations and discussions underlined some particular issues that might require consideration at the third meeting of the SED on the basis of the forthcoming contributions of WGII and WGIII to AR5, including:

(a) Risk management, including the relationship between risk and overshooting of the goal, geographical distribution of risks given regional differences in impacts and in economical or other costs of adaptation for various levels of warming;

(b) Underlying assumptions, feasibility and cost of impacts, mitigation, and adaptation in terms of RCPs and other scenarios considered by the IPCC, as well as temporal aspects of emission pathways while considering aspects such as short-lived GHGs and commitments in carbon infrastructure.

99. We believe that our approach to the SED meeting worked well, and we will continue to consider the two themes of the review in parallel, maintaining the balance between them in terms of the time allocated to them, the format of activities, and the experts and panelists invited from developed and developing countries. We also believe that an adequate amount of time was allocated to our meeting and we aim to make similar arrangements for the consideration of the contributions of WGII and WGIII to AR5.

Annex III

Summary report on the third meeting of the structured expert dialogue

I. Introduction

A. Mandate

1. The Conference of the Parties (COP), at its eighteenth session, decided that the structured expert dialogue (SED) should consider on an ongoing basis, throughout the 2013–2015 review, the material from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) as it becomes available, through regular scientific workshops and expert meetings, and with the participation of Parties and experts, particularly from the IPCC.[1] The contribution of Working Group II to the AR5[2] (AR5 WGII) and the contribution of the Working Group III to the AR5[3] (AR5 WGIII) were approved and accepted by the IPCC in March and April 2014, respectively.

2. At their thirty-ninth sessions, the Subsidiary Body for Scientific and Technological Advice (SBSTA) and the Subsidiary Body for Implementation (SBI) requested us, the co-facilitators of the SED, to organize its meetings in 2014 in conjunction with the fortieth and forty-first sessions of the subsidiary bodies.

3. In response to the above-mentioned mandate, we convened the third meeting of the SED (SED 3) during the fortieth sessions of the subsidiary bodies, to make a contribution to the assessment of the adequacy of the long-term global goal and the overall progress made towards achieving it, to the extent possible, on the basis of AR5 WGII and WGIII. Prior to SED 3, we provided Parties with an information note outlining our approach to the organization of the meeting.[4]

B. General objective and approach for the meeting

4. The goal of SED 3 was to make a contribution to the assessment of the adequacy of the long-term global goal and the overall progress made towards achieving it, to the extent possible, on the basis of AR5 WGII and WGIII.

5. Accordingly, we organized SED 3 in a similar manner to previous SED meetings as a fact-finding exchange of views between experts and Parties. IPCC experts presented findings from AR5 WGII and WGIII and highlighted their relevance to both themes of the 2013–2015 review (see para. 8 below). These presentations were followed by a moderated discussion guided by questions prepared by the co-facilitators[5] based on questions provided by Parties through their submissions,[6] questions from participants, and additional questions provided by some Parties before each part of the meeting.

[1] Decision 1/CP.18, paragraph 86(a).

[2] *Climate Change 2014: Impacts, Adaptation and Vulnerability*. Available at <http://www.ipcc.ch/report/ar5/wg2>.

[3] *Climate Change 2014: Mitigation of Climate Change*. Available at <http://www.ipcc.ch/report/ar5/wg3>.

[4] Available at <http://unfccc.int/8622.php>.

[5] For the list of questions, please see the SED 3 agenda, available at <http://unfccc.int/8622.php>.

[6] SBSTA 39 and SBI 39 agreed to continue consideration of the volumes of IPCC AR5 as they become available; other inputs as listed in decision 2/CP.17, paragraph 161; questions put forward by Parties to ensure a balanced consideration of these inputs; and the views of Parties on both themes of the 2013–2015 review, in accordance with decision 1/CP.18, paragraph 88, and requested Parties to submit their views on the future work of the SED, including the further use of different sources of information (FCCC/SBSTA/2013/5, paragraphs 134–135 and FCCC/SBI/2013/20, paragraphs 168–169). The submissions from Parties are available at <http://unfccc.int/science/workstreams/the_2013-2015_review/items/7590.php>.

II. Summary of the proceedings

6. SED 3 consisted of four parts and was held on 6–8 June 2014 at the Maritim Hotel in Bonn, Germany, during the fortieth sessions of the subsidiary bodies, and was open to all Parties and observers. Part 1 was held on Friday, 6 June (4–7 p.m.), part 2 was held on Saturday, 7 June (10 a.m.–1 p.m.) and parts 3 and 4 were held on Sunday, 8 June (10 a.m.–1 p.m. and 3–6 p.m., respectively).

7. The meeting was chaired and moderated by us, the co-facilitators. Christiana Figueres, Executive Secretary of the UNFCCC secretariat, opened the meeting, underlining that the purpose of the SED is to build a bridge between science and policy. While recognizing that science is always a few steps ahead of policy, she stressed that the AR5 highlights the urgent need for policy to "catch up", both in the short term to bend the emissions curve to stay on the path to limit global warming below 2 °C, and in the long term. She added that the 2015 agreement[7] should therefore provide the basis for reaching a level where the same amount of greenhouse gases (GHGs) are absorbed as are emitted.

8. The discussion at the meeting focused on the two themes of the review: the adequacy of the long-term global goal in the light of the ultimate objective of the Convention (theme 1), and overall progress made towards achieving the long-term global goal, including a consideration of the commitments under the Convention (theme 2).

9. With respect to AR5 WGII, the topics addressed included: the observed impacts and projected risks associated with various levels of warming, including warming to 2 °C or 1.5 °C; human interference with the climate system; the link between socioeconomic pathways and climate change risks; adaptation options, needs, opportunities and associated costs; climate-resilient pathways; and the link between adaptation, mitigation and sustainable development.

10. As regards AR5 WGIII, the topics addressed included: transformation pathways and limiting warming to 2 °C or 1.5 °C; sectoral and cross-sectoral mitigation pathways; trends in the stocks and flows of GHG emissions and their drivers; international cooperation on mitigation; policy, socioeconomic, equity and ethical aspects of climate change; and cross-cutting mitigation investment and finance issues.

11. In preparing the questions that guided the discussions in each part of SED 3, we took into consideration the above-mentioned questions submitted by Parties, our experience with the first and second meetings of the SED, as well as overarching issues such as: the requirements and limitations associated with the long-term goal to limit the increase in the global average temperature below a specific level, such as 2 °C or 1.5 °C above pre-industrial levels;[8] the costs and benefits of limiting warming to a given level; the level of unacceptable global warming; and the consequences of delaying action. The mandate of the 2013–2015 review requests the SED to address such issues; SED 3 enabled us to obtain the scientific information relevant to the quest for reliable answers to such questions.

12. **Part 1** of the meeting opened with a scene-setting presentation made by an IPCC expert on the overarching findings and new approaches of AR5 WGII that are relevant to both themes of the 2013–2015 review. The presentation was followed by a discussion guided by questions. Subsequently, presentations on theme 1 of the review focused on the past and current impacts of, as well as the projected risks posed by, climate change from global and regional perspectives with a view to assessing the adequacy of the long-term global goal using inputs from AR5 WGII, and outlined the climate risk management framework and the mapping of the so-called 'solution space'.[9]

13. **Part 2** started with presentations on impacts, adaptation and vulnerability issues relevant to theme 2 of the 2013–2015 review and explored: the link between socioeconomic pathways and the risks posed by climate change; adaptation options, needs, opportunities and associated costs; climate-resilient pathways and the relationship between adaptation, mitigation, and sustainable development in the context of assessing progress

[7] The COP, by decision 1/CP.17, launched a process to develop an agreement under the Convention applicable to all Parties, to be adopted at COP 21 in 2015 and to come into effect and be implemented from 2020.

[8] Decision 1/CP.16, paragraph 4.

[9] See figure SPM.8 in the summary for policymakers in AR5 WGII, available at <http://ipcc-wg2.gov/AR5/images/uploads/WG2AR5_SPM_FINAL.pdf>.

made towards achieving the long-term global goal. The presentations were followed by a substantive discussion guided by questions.

14. **Part 3** of the meeting opened with a scene-setting presentation by an IPCC expert on the overarching findings and new approaches of AR5 WGIII that are relevant to both themes of the 2013–2015 review. The presentation was followed by a discussion guided by questions. Subsequent presentations on theme 1 of the review focused on transformation pathways and limiting warming below 2 °C or 1.5 °C, including the likelihood of limiting global warming at those levels and the urgency of the action required to move towards such pathways; sectoral and cross-sectoral mitigation pathways; mitigation potentials, costs and technologies; investment patterns and international cooperation; regional development and cooperation; and national and subnational policies and institutions.

15. **Part 4** started with presentations on theme 2 of the 2013–2015 review, exploring progress made in: trends in stocks and flows of GHGs and their drivers; climate mitigation policy, value judgment, and ethical and equity concepts and considerations in the context of sustainable development; and cross-cutting investment and finance issues, with an assessment of the progress made towards achieving the long-term global goal. As in the previous three parts, the presentations were followed by a substantive discussion among experts and Parties guided by questions.

III. Summary of the discussion

A. Part 1: setting the scene for considering the contribution of Working Group II to the Fifth Assessment Report

1. Presentation by an expert

16. Part 1 of the meeting opened with a scene-setting presentation by Mr. Chris Field, Co-Chair of IPCC Working Group II (WGII), who outlined the overarching findings and new approaches of AR5 WGII that are relevant to both themes of the 2013–2015 review. He described the **concept of risk of climate-related impacts**, explaining that risk emerges from the overlap of climate-related hazards with vulnerability and exposure of human and natural systems (figure 20). The extent of climate change can therefore be controlled not only by through mitigation, but also by moderating and managing the risks of climate change (i.e. by any actions addressing vulnerability, exposure and/or hazards). Consequently, changes in both the climate system and socioeconomic processes, including adaptation and mitigation, are drivers of hazards, exposure and vulnerability.

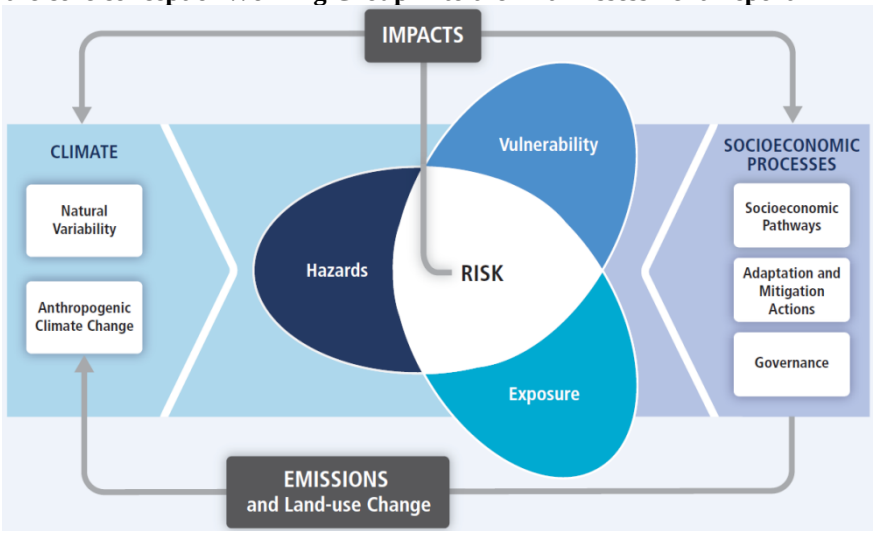
17. Mr. Field noted that the **observed impacts of climate change are consequential and wide-ranging**, spanning across all regions and sectors (figure 21) and that, compared to the IPCC Fourth Assessment Report (AR4), the confidence levels related to the impacts of climate change are higher in the AR5. He said that we should ask ourselves whether these impacts, individually or collectively, have already crossed the threshold as defined in Article 2 of the Convention, and presented some examples of these impacts, namely: the consistent mass loss of glaciers, including that of the Himalayan glaciers; forest die backs; and wheat and maize yield decreases.[10]

18. He noted that **increasing magnitudes of warming increase severe, pervasive and irreversible impacts,** and that the decisions taken over the next two decades with regard to mitigation and adaptation will affect the risks of climate change throughout the twenty-first century. He presented two world maps prepared by IPCC Working Group I (WGI) showing projected temperature increases for the twenty-first century according to representative concentration pathway (RCP) scenarios RCP2.6 and RCP8.5, and noted that two eras can be distinguished (figure 23): a near-term era (the next few decades) where the temperature increase does not significantly depend on mitigation efforts and, therefore, adaptation provides the main options to control risks, while recognizing the essential role of mitigation investments in addressing climate change in the long term; and

[10] For details of observed regional impacts, see table SPM.A1 in the summary for policymakers in AR5 WGII, available at <http://ipcc-wg2.gov/AR5/images/uploads/WG2AR5_SPM_FINAL.pdf>.

a long-term era, where there is a large difference between the projected global warming for RCP2.6 and RCP8.5. For RCP8.5, Mr. Field noted the significantly higher increase in projected temperature for land and oceans and, consequently, the associated risks compared with RCP2.6.

Figure 20
Illustration of the core concept of Working Group II to the Fifth Assessment Report



Source: Summary for policymakers in the contribution of Working Group II (WGII) to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change, figure SPM.1. The figure illustrates the constituents of 'risk' – the fundamental concept used throughout AR5 by WGII.

19. With respect to the **projected impacts** of future climate change and the importance of the rate of change, Mr. Field described a graph showing the maximum speed at which terrestrial species can move across landscapes depending on the rate of climate change, which illustrates that RCP6, the **impacts of climate change on many habitats are occurring faster than the estimated maximum speed at which most groups of organisms can move**. The impacts of climate change are therefore outrunning the speed at which ecosystems can be expected to possibly shift in order to adapt to these changes.

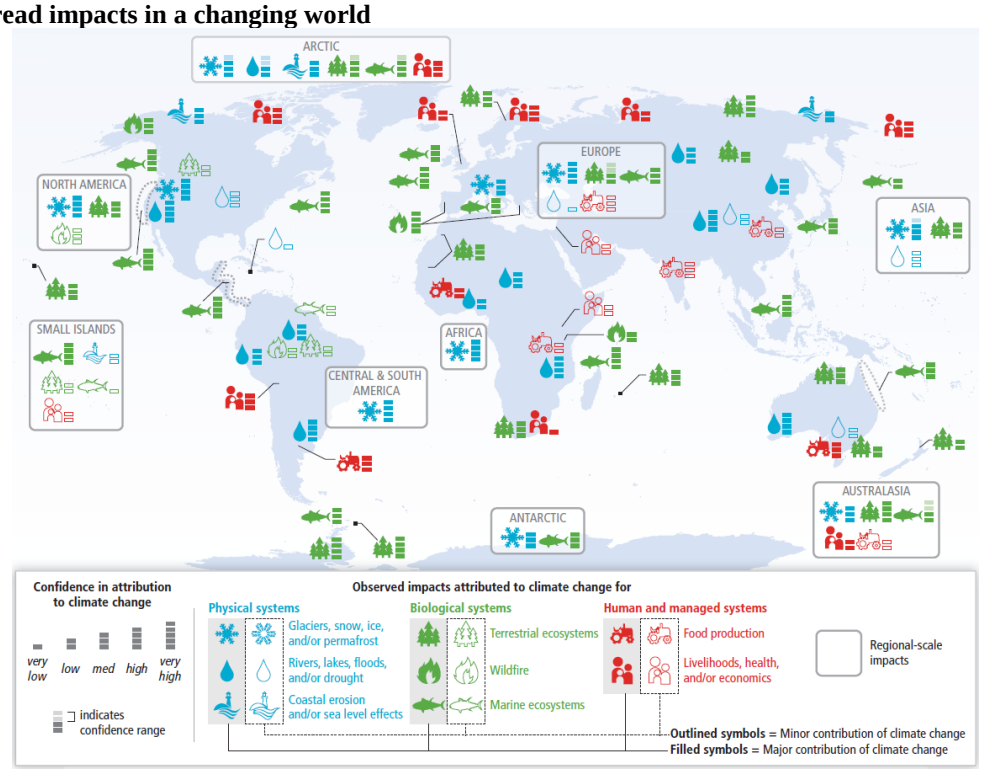
20. As regards transitioning from framing climate change in terms of temperature to **framing it in terms of risks**, he explained that one way to assess the adequacy of the long-term global goal could be to **examine the projected level of risk at 2 °C and question whether it should be decreased**. He explained that the assessment for each risk is based on an estimate of its current level, the level for the near term, and the level following a temperature rise of 2 °C and 4 °C at the end of the twenty-first century, as well as the prospects of reducing this risk based on the expert judgment of the WGII experts (figure 22). The benefits of investing in mitigation are shown by the difference in the level of risk for 2 °C and 4 °C. The grey area of each bar denoting the level of risk in figure 22 below illustrates the benefits of investing in adaptation. In the near term, the level of risk is often the same or similar for both RCP2.6 and RCP8.5.

21. Mr. Field stressed that there is a **limited prospect for risk to be reduced by adaptation action in a 4 °C warmer world**, but that there are still **significant opportunities for adaptation in a 2 °C warmer world**. However, under all of the assessed scenarios, some residual risk from adverse impacts remains. He presented examples of the assessment of key risks and prospects for adaptation in Australia and for the oceans.

22. Mr. Field explained that AR5 WGII identified **eight key climate-related risks** that span across all sectors and regions, which were identified based on expert judgment, and illustrated these risks for the main world regions. The risks can be **assessed according to the ethics, values and priorities of the various relevant stakeholders**. Furthermore, **five** integrative **reasons for concern** (RFCs) provide a framework for summarizing the key risks across sectors and regions, namely: unique and threatened systems; extreme weather events; the distribution of impacts; global aggregate impacts; and large singular events (figure 23). The first three categories are difficult to monetize. The forth category tends to be most consistent with monetization in comparison with mitigation, but does not include "all the things we care about". The last category, which also includes

irreversible impacts resulting from systems crossing tipping points, such as major ice sheet loss and a sea level rise of several metres, is also difficult to evaluate comprehensively (e.g. assessing the impacts of all major coastal cities in the world disappearing).

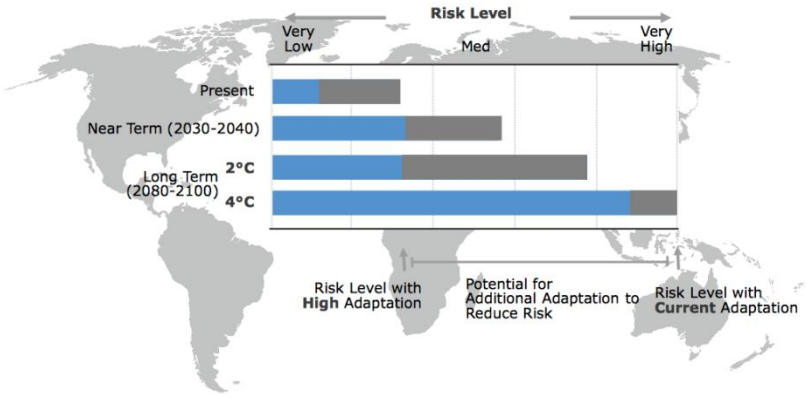
Figure 21
Widespread impacts in a changing world



Source: Summary for policymakers in the contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.2(A). The figure shows that various attributed impacts have been found in all sectors and regions, albeit with significant differences.

23. In concluding, he underlined that addressing **climate change involves managing risk**. Therefore, in order to assess the adequacy of the long-term global goal, a key element is the assessment of **when the scale** (e.g. frequency and severity) **of impacts results in a transition from 'acceptable' to 'unacceptable' at the local level**.

Figure 22
Assessing risk



Source: Slide 13 of the presentation by Mr. Chris Field (Intergovernmental Panel on Climate Change), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/0_field_sedpart1.pdf>. The figure explains the risk assessment approach adopted by Working Group II to the Fifth Assessment Report.

2. General discussion

24. The ensuing discussion was guided by the following questions:

(a) What does AR5 WGII tell us about the key risks, shifts in key risk patterns and potential benefits related to climate change?

(b) How can risks be reduced through adaptation and mitigation?

(c) How reliable are the projections of risks and how can they be used for decision-making at the global level?

(d) What are the options for managing risks through adaptation and sustainable development?

25. In response to a question on the **definition of 'moderate' and 'high' adaptation,** and if 'high' adaptation implies action that is not only plausible but also possible, the expert explained that the WGII authors took into account regional development pathways when assessing 'moderate' and 'high' adaptation, and that 'high' adaptation relates to the physical limits of adaptation and is generally indicative of potential for adaptation free of serious financial constraints (see para. 57). He added that even with 'high' adaptation, residual risks remain under all scenarios, which could trigger the decision to aim for a lower temperature limit than 2 °C.

26. One Party asked how to characterize **the point**, in terms of levels of warming, **at which there is no longer adaptation but loss**. The expert said that the **transition from adaptation to loss** depends on the scale, but that, in general, when proactive adaptation by communities to pursue sustainable development is eroded, adaptation is difficult. For example, a forced relocation is considered to be adaptation if development aspirations continue to be met. If there is still a residual risk with 'high' adaptation, this is considered to be loss and damage. In terms of WGII products, if there is still a residual risk with a 2 °C temperature rise with 'high' adaptation, then that equates to damage.

27. In response to a request for more information **on the consequences of a 1.5 °C temperature rise, as opposed to a 2 °C temperature rise,** the expert clarified that AR5 WGII contains very limited assessment of the impacts of a 1.5 °C warming because of the scarce literature available to assess the impacts resulting from this limit. The RFCs presented in figure 23 summarize some of the risks related to a 1.5 °C temperature rise. He added that **near-term risk, where warming is around 1.5 °C, could serve as an operational tool to provide an approximate indication of the impacts of a 1.5 °C long-term warming**.

28. Responding to a question on how to **cooperate internationally on adaptation**, taking into account the intrinsically local nature of adaptation, the expert underlined the importance of adaptation in the global strategy to address climate change, as well as the interplay between adaptation and mitigation action. He added that adaptation relies largely on decisions made at the local, regional and national levels.

29. One participant was of the view that AR5 WGII provides very important information, including on the observed impacts and future risks of climate change, as well as opportunities for effective action to reduce such risks. **A risk framework could help to improve the decision-making process on climate change** and, in the context of urgency of action, adaptation provides the main opportunity for developing countries to address climate risks in the short term. Adaptation is therefore the highest priority for developing countries and, in this context, international cooperation on adaptation plays an important role.

B. Part 1 – theme 1: the adequacy of the long-term global goal in the light of the ultimate objective of the Convention based on the contribution of Working Group II to the Fifth Assessment Report

1. Presentations by experts

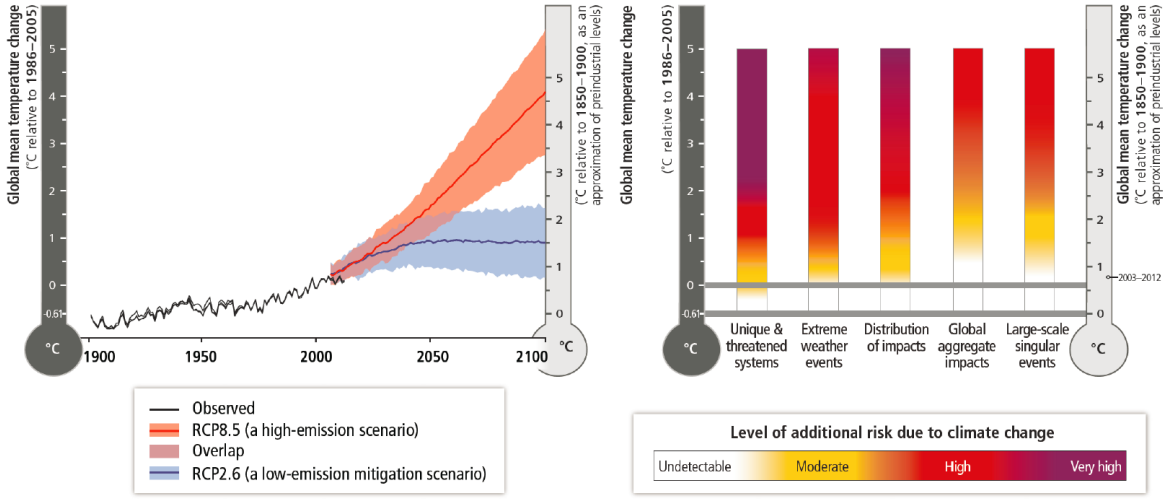
30. Mr. Joern Birkmann (IPCC) made a presentation on **human interferences with the climate system** and RFCs. He explained that the **key climate-related risks and RFCs** can be used as **vehicles to understand "dangerous anthropogenic interferences with the climate system"** in view of the long-term global goal, assuming various upper limits of global warming and a range of levels of exposure and vulnerability. The key risks are potentially severe adverse consequences for humans and socio-ecological systems resulting from the

interaction of hazards linked to climate change and the vulnerability of exposed societies and systems. The criteria for considering that a risk is 'key' is based on: the magnitude of the risk (not of the hazard); the probability that significant risks will materialize and their timing; the irreversibility and persistence of conditions that determine risks;[11] and the limited ability to reduce the magnitude and frequency or other characteristics of hazardous climate events and trends, and the vulnerability.

31. Mr. Birkmann explained that the WGII experts identified, in various chapters of AR5 WGII, over 80 regional and sectoral risks, including the hazards and key vulnerabilities that generated such risks, as being the most pressing based on the above-mentioned criteria. The risks were then condensed into **eight key risks** to avoid repetition. He provided some examples of the key risks, such as risks of death, injury or disrupted livelihoods in low-lying coastal zones (reflected in RFCs 1–5 in figure 23), risks of severe ill-health and disrupted livelihoods for large populations due to inland flooding in some regions (RFCs 2 and 3), and systemic risks due to extreme weather events leading to a breakdown of infrastructure networks and critical services (RFCs 2–4).

Figure 23

A global perspective on climate-related risks



Source: Summary for policymakers in the contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, assessment box SPM.1 figure 1. The figure shows how the additional risks associated with the five reasons for concern are affected by a low-emission scenario (RCP2.6) compared with a high-emission scenario (RCP8.5).

Abbreviation: RCP = representative concentration pathway.

32. Underlining the **multidimensional nature of vulnerability**, Mr. Birkmann noted that addressing the different dimensions of vulnerability, such as its social, economic, environmental and institutional aspects, and accounting for the dynamics of exposure and vulnerability are as important as assessing the degree of warming and its implications for weather extremes. With regard to **the dynamics of exposure**, Mr. Birkmann noted that even if the climate remains unchanged, future risk could increase. For example, in China, more people will be exposed to climate hazards as a result of population increase.

33. Mr. Birkmann explained that the eight key climate-related risks were aggregated and translated into five RFCs, which represent the level of additional risk due to climate change (figure 23). He also compared the RFCs identified in the Third, Fourth and Fifth Assessment Reports to illustrate that the past trend and scenarios for future development trends indicate that **an increase in exposure to climatic hazards will be experienced in most regions**.

34. Mr. Christian Huggel (IPCC) addressed the **observed impacts and projected key sectoral risks**, as well as the **potential and opportunities for adaptation**, with a focus on ecosystems, food production and security, economic impacts and livelihoods (aspects related to Article 2 of the Convention). He explained that WGII

[11] This refers to hazards as well as to societal changes.

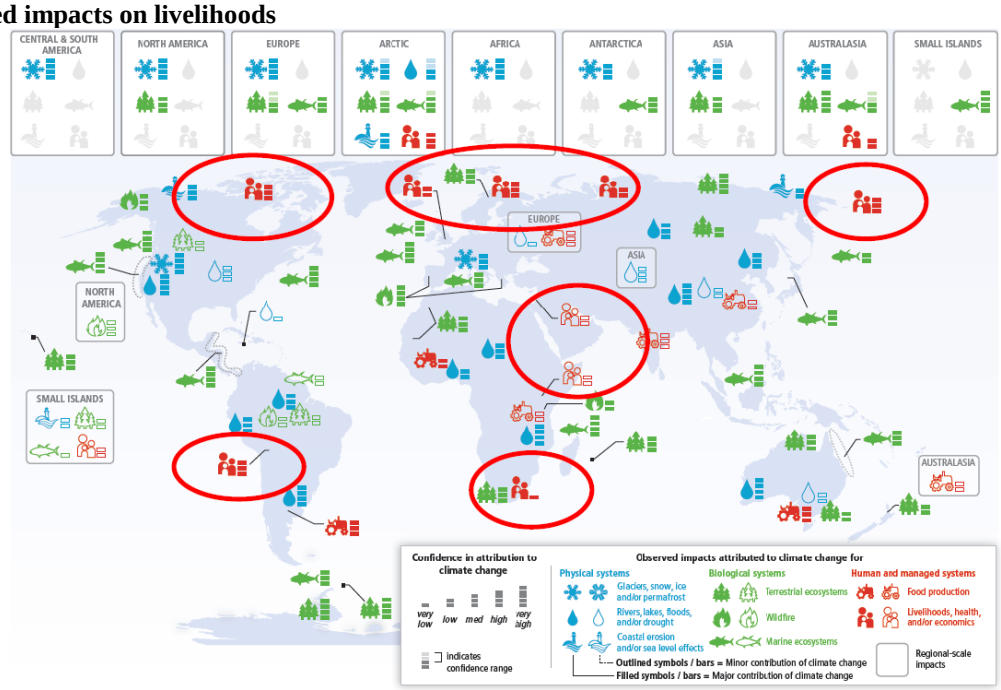
considered chains of impacts,[12] noting that the observation and attribution of impacts to climate change and the projection of future risks becomes more difficult further down the chain, due to the influence of other convoluting factors.

35. Mr. Huggel noted that **non-climatic factors are currently the dominant drivers of observed changes in terrestrial ecosystems**, with the exception of highly temperature-sensitive systems, such as the polar regions, high mountains and the tropics. It is worth noting that for these systems, the difference in **projected risks** between a warming of 1.5 °C and 2 °C is significant. Moreover, changes will continue to occur for many decades, even if global warming stops immediately. For example, glaciers worldwide are not in balance with the current climate (lagged response), and there can be significant differences between the level of local temperature increase and the global mean figure. Further, the delayed response in many ecosystems is key to identifying tipping points. Rising temperatures will lead to many changes, such as shifts in freshwater species, water-quality problems and an increase in the risk of forest fires.

36. On the issue of **food production and security**, Mr. Huggel noted that negative impacts of climate change on agricultural crops and marine fisheries have already been observed. Projected risks indicate an increase in negative impacts on crop yields with increasing warming, with all aspects of food security potentially being affected by climate change. **Economic losses** from extreme weather events have been increasing, mainly due to observed increases in exposure. Future losses will also be dominated by exposure (see figure 28), while vulnerability and losses due to climatic factors will also increase.

37. There is new, emerging and clearer evidence of climate change impacts on **livelihoods** (figure 24). The best evidence of these observed impacts comes from temperature-sensitive regions, such as the polar regions and high mountains. Climate change impacts are expected to slow down economic growth, jeopardize poverty reduction efforts and erode food security.

Figure 24
Observed impacts on livelihoods



Source: Slide 15 of the presentation by Mr. Christian Huggel (Intergovernmental Panel on Climate Change), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2_huggel_sedpart1.pdf>. The figure shows that various attributed impacts have been found in all sectors and regions, albeit with significant differences.

[12] For example, a temperature increase in Peru's mountainous areas will lead to glacier shrinkage, changes in water resources, and impacts on crops and cattle, as well as on livelihoods, in that area.

38. Generally speaking, the key question with regard to **projection of risk** is whether ecosystems will be able to render key services and functions under various emission pathways. **Climatic stressors will play an increasingly important role, which will then be largely determined by the emission pathway chosen**.

39. **Adaptation can effectively reduce risks if implemented in association with integrative strategies**; however, **it is restricted by a range of limits,** such as those related to space, high-emission pathways or constraints in adaptive capacity. The adaptive capacity of many ecosystems and species is insufficient for medium to high warming scenarios. In some systems, such as the cryosphere, the Arctic, high mountains or coral reefs, such limits have already been reached.

40. Ms. Penny Urquhart (IPCC) presented the observed and projected **regional impacts, risks and potential for adaptation**. Substantial adaptation deficits have been observed in some regions[13] and there is differential vulnerability to key regional risks (figure 25). Many key risks constitute particular challenges for the least developed countries and for vulnerable communities. Vulnerability is linked to multidimensional inequalities, often created by uneven development processes. She provided some examples of such differential vulnerabilities in relation to: **food insecurity and malnutrition** (high and very high risks in Africa, Asia, and Central and South Asia in relation to a global temperature increase of 4 °C); **flooding** (with most of the population affected in East, South-East and South Asia owing to an increase in exposure and vulnerability); and **hot spells and heatwaves** (in Europe, Asia and Australia).

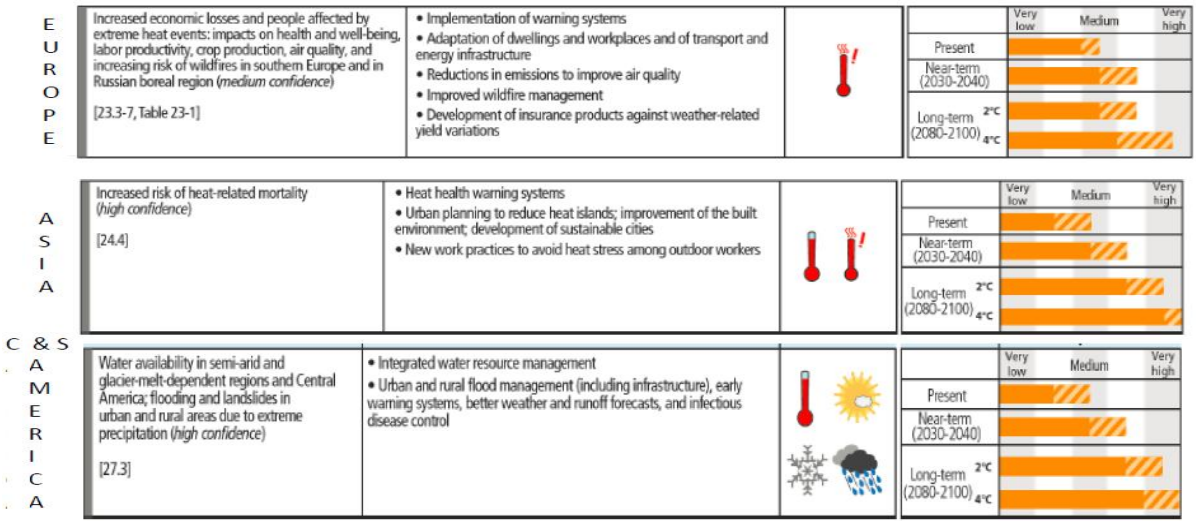
41. With regard to **regional adaptation trends**, Ms. Urquhart described the development of adaptation actions and policies in all regions, noting growing experience in Asia, Africa, Central and South America, small islands and the Arctic, through a combination of traditional and scientific knowledge and community-based adaptation. Common adaptation trends for these regions include ecosystem-based adaptation, growth of resilient crop varieties, expansion of agro-ecological approaches, and climate forecast and early warning systems. However, most adaptation in developing regions remains autonomous, reactive and unsupported, and not at scale. In Europe and North America there is greater involvement of adaptation governance systems, as well as more capacity, experience and resources at the municipal level.

42. Ms. Urquhart noted that **while some regional risks can be reduced through adaptation**, **others may be intractable**, such as threats to freshwater, terrestrial and marine ecosystems in the polar regions, threats to low-lying areas of small islands, and reduced biodiversity in and coastal protection from coral reefs in Australasia, small islands around the world and the east coast of Africa. While risks related to flooding can be reduced by adaptation from the category medium to very low in Europe in the case of a 2 °C temperature rise, flooding risks remain medium to high even with adaptation for the same amount of warming in Asia and in Central, South and North America, and would become more widespread with a 4 °C temperature rise.

[13] For example, adaptation deficits have been observed for risks relating to food security in some parts of Africa, declining food production and quality in Central and South America, and food production in some regions of Australia.

Figure 25

Examples of regional risks under high adaptation with a 2 °C temperature increase



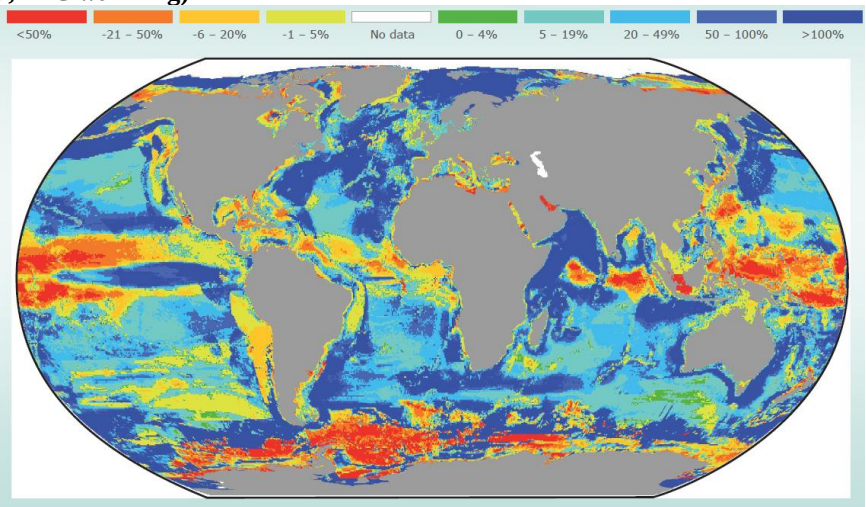
Source: Slide 12 of the presentation by Ms. Penny Urquhart (Intergovernmental Panel on Climate Change), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/3_penny-sedpart1.pdf>. The figure shows how the risk assessment approach of figure 3 was applied in a regional context.

43. Significant **adaptation challenges are distributed unevenly across and within regions**, and some risks may be reduced in some regions but not others. For example, all nine assessed risks for Africa remain high or very high under current levels of adaptation under a 2 °C warming scenario. Adaptation policies and measures will be more effective if they address the underlying causes of poverty and inequality. However, many residual impacts will remain under a 2 °C warming scenario, even with 'high' adaptation, and these impacts will significantly increase under a 4 °C warming scenario for all regions.

44. Mr. Hans-Otto Pörtner (IPCC) made a presentation on **climate-related impacts on the world's oceans**. He outlined climate-related ocean issues, noting the key role of oceans in the climate cycle and the influence of human activities on ocean conditions. Temperature increase is currently the predominant driver of ongoing global changes, leading to shifts in biogeographical distributions of marine organisms. These changes are projected to continue in the future, leading to shifting stocks across fishing zones as organisms migrate to stay within their thermal tolerance range. For commercial species, an impoverishment at lower latitudes with a shift of stocks to higher latitudes is projected by the mid twenty-first century with a 2 °C warming (figure 26). These changes will result in risks to humans and infrastructure. Human adaptation options include the large-scale relocation of industrial fishing activities, but such options are limited for artisanal local fisheries and only exist in the near term, even for a 2 °C temperature increase.

Figure 26

Change in maximum catch potential (2051–2060 compared with 2001–-2010, *Special Report on Emissions* Scenarios, A1B, 2 °C warming)



Source: Summary for policymakers in the contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.6(A). The figure illustrates the significant projected change in a marine ecosystem service–based, fishery-related parameter for a global mean warming of only 2 °C.

45. As regards the degree of **ocean acidification**, projections depend on the emissions scenario and are associated with an uneven global pH distribution in the oceans and higher acidification in the polar regions. The human adaptation option of shifting to using more resilient species or protecting habitats with low natural carbon dioxide (CO_2) levels only exists in the near term and not in the long term, even for a 2 °C temperature increase, owing to the sensitivity of species, especially with a high level of acidity of the oceans.

46. Mr. Pörtner noted that **oxygen levels in oceans are decreasing** and explained that the tolerance of organisms to low oxygen levels depends on their complexity, and larger body size organisms generally tend to be more vulnerable. Areas devoid of animal life are expanding. Underlining the **interaction of warming, acidification and hypoxia**, he stated that in animals, the strongest impacts are expected where these factors combine, indicating that assessments based on individual drivers are conservative.

47. On the issue of **sea level rise, beyond 2100** a rise of up to six or seven metres in 2500 is projected,[14] depending on the emissions scenario, with a high level of uncertainty. An examination of palaeo-analogues reveals that a sea level rise of this magnitude occurred in the Pliocene age, when atmospheric CO_2 concentrations were 400 ppm, and in the last interglacial period, when temperatures were about 2 °C above pre-industrial levels.

48. Regarding the impacts of climate change on **vulnerable ecosystems**, Mr. Pörtner focused on warm-water coral reefs and the Arctic sea ice ecosystem. With respect to warm-water coral reefs, the impacts include the bleaching and die off of corals, and an increase in predators. **To protect at least 50 per cent of the coral reefs, the global mean temperature change would have to be limited to 1.1–1.4 °C** (without taking into account the effects of ocean acidification), especially given the lack of evidence to demonstrate that corals can evolve significantly on decadal timescales and under continually escalating thermal stress. As regards the Arctic sea ice ecosystem, summer sea ice is projected to be marginalized and to disappear by the mid twenty-first century under the highest warming scenarios.

49. In conclusion, Mr. Pörtner underlined that, with respect to ocean-related risks, **adaptation "buys time", but is very limited for some systems, such as the polar regions and coral reef systems**.

[14] See the contribution of WG I to the AR5, table 13.8, available at <http://www.ipcc.ch/report/ar5/wg1>.

2. General discussion

50. The ensuing discussion was guided by the following questions:

(a) What impacts has the world observed, and what are the projected key risks and opportunities for the natural, human and managed systems at various levels of temperature increase?

(b) What is the regional variability of observed impacts and projected key risks and opportunities under various warming scenarios?

(c) Is there a difference in impacts, on both oceans and land, of a global warming of 1.5 °C and 2 °C relative to pre-industrial levels?

(d) What level of warming could be interpreted as dangerous and for what reasons, considering the associated scientific uncertainties?

(e) What uncertainties remain? What is their role in a risk management context? Are they calling for a global policy response?

(f) How do the above-mentioned findings relate to the adequacy of the long-term global goal in the context of policymaking in the UNFCCC process?

51. **Regarding the relationship between mitigation and adaptation**, a Party asked for clarification as to what extent these two actions depend on each other. An expert pointed to the existence of co-benefits and synergies between adaptation and mitigation actions. He said that the most attractive options for actions are those that have a mitigation and adaptation component and contribute to sustainable development. Another Party underlined the benefits of **setting mitigation and adaptation goals** and fully considering the risks of different pathways, which is important in the context of the 2013–2015 review. Responding to a question on the urgency of taking action on climate change and the long-term perspective, an expert noted the profound benefits of early action, adding that mitigating to RCP2.6 depends heavily on rapid action, in a manner that society has never before experienced.

52. **With regard to the assessment of the 1.5 °C limit**, a Party asked if more literature would be made available in the near future. In response, an expert referred to recent literature on the possible irreversible loss of the West Antarctic ice sheet, noting that if these still tentative findings are to be further confirmed and strengthened, the level of risks for RFC 5, including such a large-scale singular event with its inevitable and significant sea level rise, would have to be reassessed and increased. Another Party added that there is now a case for reviewing the level of risk associated with the RFCs for sea level rise since there would already be a high risk under the 2 °C warming scenario based on this new information.

53. Regarding the **difference in impacts**, on both oceans and land, **of global warming of 1.5 °C and 2 °C** relative to pre-industrial levels, an expert reiterated that literature available to assess the 1.5 °C limit (see para. 27 above) is scarce. Another expert stressed that this may also be due to the fact that many scientists are unaware of the fact that a 1.5 °C warming is being discussed by policymakers. He added that the understanding of some physical systems, such as glaciers and permafrost, hinder the response to this question. For agricultural and human systems, the difference between a 1.5 °C and a 2 °C temperature rise is becoming increasingly difficult to assess. Yet another expert underlined the need to address this question in terms of the differences between vulnerability and exposure at these temperature level rises. To this end, for some regions the consequences of a 2 °C warming will be significantly different from those created by a 1.5 °C warming, in particular for low-lying coastal regions. An expert noted the need to consider large-scale changes and pointed to the benefits of the 1.5 °C warming scenario for vulnerable ecosystems such as coral reefs and the polar regions.

54. An expert stressed that current levels of warming are already causing impacts beyond the adaptive capacity of many people, and that there would be significant residual impacts even with a 1.5 °C warming (e.g. for sub-Saharan farmers), emphasizing that it would be preferable to move the limit downwards to 1.5 °C. Another expert noted that some technologies and policies required to effectively deal with a 1.5 °C temperature rise may negatively impact poverty reduction efforts. Yet another expert recalled that impacts are already occurring and that risk will increase with the degree of temperature rise. Therefore, even if studies that identify different risks at 1.5 °C and 2 °C are scarce, there is a high likelihood of meaningful differences between these temperature limits as regards the level of risk of extreme events or tipping points. He then raised the question whether the long-term global goal is a ‘guardrail’ or societally determined agreement on an acceptable limit. **He**

emphasized that the 'guardrail' concept is inadequate, as impacts are already occurring and having significant effects. Therefore, the long-term global goal should be the limit above which the impacts will become too widespread and unacceptable across the RFCs; setting this limit depends on the values and interests of Parties.

55. **On the issue of regional differences**, a Party underlined the importance of a 1.5 °C temperature rise limit for some regions, as well as the disproportionate distribution of impacts and differences in the amount of literature for some regions. He asked about the risks of conflicts at the local and regional levels, especially when water resources are become scarcer. An expert said that it is often the case that the least amount of research is conducted and literature is available for the most vulnerable regions, stressing the need for more research. He added that this need is most acute in relation to projecting impacts and characterizing risk, particularly for high degrees of warming. He also noted a growing volume of literature on human security and indicated that the issue of conflicts would be discussed in part 2 of the meeting. Another expert added that the IPCC experts made great efforts to include traditional and indigenous knowledge in their assessment, and that there have been significant improvements in the assessment of risks related to high mountain ecosystems, in particular the Andes and the Himalayas.

56. In response to a question relating to the **regional and global food security risk at different levels of warming**, taking into account the large differences in risks between the local and regional levels even under the 1.5 °C and 2 °C warming scenarios, an expert stated that for any level of warming, regional differences are going to be large, thereby underlining the importance of using a risk-based framework. Another expert pointed to the chapter of AR5 WGII on Africa, where the levels of risk for some countries such as South Africa and Zimbabwe are higher than at the global level with, for example, a reduction in maize yields of up to 30 per cent by 2050.

57. One Party asked about the **disconnect between the prospects for 'high' adaptation at the global level and realities at the regional level**, in particular for regions where some impacts are projected to be irreversible, such as the polar regions and small island developing States. An expert clarified that the reality on the ground was built into the assessment, since the experts based their assessment of 'high' adaptation on the most probable development pathways for each region using pertinent regional information, as currently available. Another Party mentioned the difference between the levels of risk at the global and local levels for the same temperature scenario, and the fact that the local temperature increase can be higher than the global mean level. Another expert replied by underlining the importance of the regional assessments, adding that regional risk could not be deducted from global scenarios.

58. Responding to a question on what can constitute a **limit to 'high' adaptation**, an expert noted that constraints to 'high' adaptation are sensitive to the particular issue and reflect the fact that adaptation is difficult to assess, particularly for long-term time frames (2040 and 2100). Another expert added that, in addition to biophysical and economic limits, which persist as long as adaptation is not seen as a cost-effective investment, limits to adaptation can be perceptional or cultural.

59. In response to a question related to timescales associated with **planetary equilibrium**, an expert noted the discrepancy between the fact that ocean warming reduces the impact of climate change, and that this may delay both attainment of the equilibrium and our response to climate change, thereby increasing the difficulty of addressing this challenge. According to the warming scenarios, the equilibrium in terms of temperature and sea level would only be reached after several centuries.

60. As regards the role of **non-climate stressors**, in particular those related to sea level rise, a Party asked if it were possible to look beyond exposure and vulnerability to identify the types of development or urbanization decisions that will drive down the climate signal. An expert pointed to lessons learned from past extreme events that could guide urbanization and development decisions, including the opportunities and limits associated with steering the urbanization process. He stressed that a better strategy is to think in terms of urbanization scenarios and define a larger protected area rather than simply defining a threshold for protected and unprotected areas. The AR5 shows that rural–urban migration is a "moving target" that should be considered within the context of land-use planning and the development of risk reduction strategies. Another expert noted that the risk framework allows for a better understanding of the role of non-climatic stressors.

61. In response to a follow-up question regarding **losses due to the placement of economic assets or human settlements and their attribution to climate change**, an expert pointed to the subtle but important difference in the definition of attribution between WGI and WGII given the nature of the systems studied. The chapter on

attribution in AR5 WGII emphasizes the need to recognize that the baselines, in particular for human systems, are constantly changing. Therefore, the literature that would enable a distinction to be drawn between anthropogenic and natural climate change in the sphere of WGII does not currently exist and future work is required, including research on methodologies. Highlighting the increasing cascading effects of impacts, another expert stated that, although there can be a clear climate signal, attribution in the strict sense is often unclear. For example, in the case of Hurricane Sandy, the major impacts came from secondary effects on infrastructure and their attribution to climate change is unclear. He noted the political interest in subdividing these components and highlighted the need to recognize the complexities involved in attribution and to consider this matter within the context of a risk management framework.

62. With respect to **progress made in determining metrics for adaptation**, an expert explained that the WGII experts moved away from using a single metric to assess adaptation needs and options, based on the recognition that the best adaptation options address multiple dimensions of vulnerability and contribute to other mitigation and sustainable development goals. It is therefore very difficult to apply an additionality criterion to evaluate the effects of adaptation investments. Adaptation options that affect the trajectory of societal development are very difficult to evaluate with a simple metric, precisely because of the simultaneous difference occurring across a multitude of aspects.

63. Responding to a follow-up question on the global and regional **consequences associated with a 50 per cent loss of coral reefs**, an expert noted that the location of the reefs would determine the magnitude of the loss, which would depend not only on many local factors influencing the fate of the coral reefs, but also on the value of the reefs in relation to the various ecosystem services they render. The total value of coral reefs, probably the most vulnerable and valuable ecosystem, is estimated at more than USD 600 billion; a 50 per cent loss would therefore be significant. He stressed that the loss of coral reefs has already begun and that the prospects for adaptation are very low. The adaptive capacity of coral reefs may only play a limited role at the present rate of temperature change and ocean acidification (limited evidence). Another expert added that there is some evidence indicating that coral reefs in the West Indian Ocean may be more resilient than those in the East Indian Ocean.

64. Responding to questions raised by two Parties **on the qualification of risk**, including on how some risks have been deemed as high and how local risks have been used to determine regional risks, an expert explained that AR5 WGII includes hundreds of diagrams depicting risks and that the challenge is to understand the meaning of these diagrams in relation to the long-term global goal and Article 2 of the Convention. He added that WGII used expert judgment on the level of risk and the possibility for adaptation based on a series of explicit criteria, in accordance with the IPCC's mandate. Another expert explained that the experts involved in compiling chapter 19 of the WGII report used information on risks from other chapters of the report to identify key risks, which were then condensed into eight key risks (see para. 31 above). Local high risks are included in the tables of the underlying report as the experts assessed not only global but also local studies and local risks (e.g. in urban areas), and identified generalizable aspects.

65. One Party asked if there are areas of change with respect to different levels of stabilization where a **rapid change in risk levels** may take place from a regional, sectoral, systemic or integrated point of view, in order to help policymakers focus on such areas. An expert explained that the WGII report not only identifies the risk levels, but also the changes in risk levels. For example, in chapter 19 of the report, hot spots have been considered (e.g. areas where risk is very high or where risk levels could change significantly). Low-lying coastal areas in Asia pose a particular challenge, in part because of their expected increase in exposure. Sub-Saharan Africa also poses a challenge, as a result of increased vulnerability and overlapping climate hazards. Focusing on these changes should make mitigation and adaptation policies more effective (e.g. policies aimed at reducing exposure or vulnerability). Another expert underlined the non-linear aspect of organisms' responses to climate stressors, noting that determining thresholds may not be a useful exercise and that it would be preferable to determine instead the degree of change that is tolerable. Yet another expert noted that it is important to study the ways in which risks interact. In terms of RFCs, these interactions are better understood for global aggregated impacts, but other RFCs should be further examined. In response to a follow-up question from Mr. Fischlin, co-facilitator, regarding the effect of mutual drivers exacerbating risks and impacts, an expert explained that climate change impacts are complicating existing risks and that societal stress is generated by multiple interacting impacts. A deeper understanding of these interactions will allow the IPCC to better estimate climate risks.

66. A Party questioned the **comparability of studies and risks** and asked **how different risks could be weighted** (e.g. comparing risks to coral reefs with risks to subsistence farming in Africa). An expert noted the

change in terminology from "vulnerability" in AR4 to "risk" in AR5. While recognizing that "vulnerability" is a more ecological concept whereas "risk" is derived from a disaster risk management perspective, he stated that the risk concept is robust and enables better comparability. However, risks for farmers could be caused by, for example, extreme events and droughts, while for coral reefs the risks could be caused by ocean acidification. Another expert commented on the challenges involved in comparing studies that use different methodologies, noting in particular the inconsistent use of estimates of adaptation costs, not all of which factor in the existing adaptation deficits, and indicated that AR5 WGII highlights these constraints.

C. Part 2 – theme 2: overall progress made towards achieving the long-term global goal, including a consideration of the commitments under the Convention based on the contribution of Working Group II to the Fifth Assessment Report

1. Presentations by experts

67. Mr. Lennart Olsson (IPCC) made a presentation on the **links between socioeconomic pathways and climate change risks**, with a focus on poverty and livelihoods. Stressing the multidimensional aspects of poverty, he said that income poverty is complemented by other dimensions, such as health, education, access to basic services and standard of living, noting that there are more people living in multidimensional poverty than there are people qualified as "poor" according to the traditional economic approach to poverty. He explained that climate change may damage six types of assets that are crucial to maintaining livelihoods, namely: natural (e.g. vegetation, soil, water, climate); human (e.g. skills); physical (e.g. land); social (e.g. mobilization capacity); financial (e.g. savings); and cultural (e.g. identity, sense of place, knowledge).

68. Mr. Olsson highlighted **three key risks** from climate change for people living in poverty and their livelihoods, namely the risks of: **deteriorating food security**; **deteriorating access to water**; and **increasing heatwaves** (figure 27). As regards the risk of deteriorating food security, he underlined that the current risk is low, but that there is little adaptation potential due to low government support or the exclusion of small-scale farmers. In the near term (2030–2040), the adaptation potential is significant but requires adaptation capacity to be strengthened. With regard to the risk of deteriorating water access, he indicated that some areas are already subject to high risks but that adaptation opportunities exist. Rainwater harvesting technologies are inexpensive but not sufficiently deployed due to social and economic constraints. Regarding the risk of increasing heatwaves, which is currently low, adaptation potential exists. However, this potential is very limited for people living in poverty in both the near term and the long term. He added that the potential for adaptation to heatwaves for those carrying out physical outdoor work is very limited, and presented a figure illustrating the integration of key climate hazards, farm work and possible diseases to determine periods of hardship, coping and recovery for each month of the year.[15]

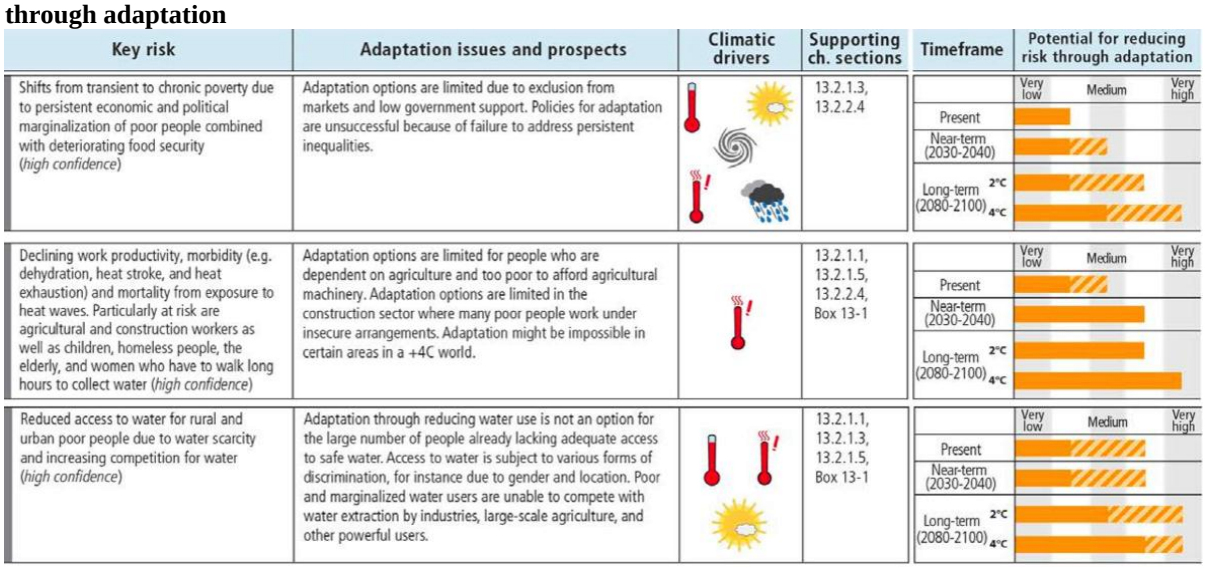
69. As regards **extreme events**, risks from hurricanes and floods are projected to increase, and in some areas migration may be an adaptation option (figure 28). There is no large difference in the number of people exposed to **flood risk** in the various RCP scenarios until 2050. However, if GHG emissions continue to increase in line with RCP8.5 or RCP6.0, the risks will become very high in the second half of the twenty-first century, and some will be beyond the limits of adaptation for the poor. Under the lower GHG emission scenarios, the flood risk remains manageable in the second half of the twenty-first century.

70. Mr. Olsson concluded that **various forms of inequality will make people more vulnerable to climate change**; **high risks already exist for the poor, both at present and in the short term**; **warming above 2 °C will imply very high risks after 2050** and in some cases may reach adaptation limits (e.g. coastal flooding and heatwaves); and **current mitigation policies may negatively impact poor people**, thereby stressing the need for policies that take into account the circumstances of those living in poverty.

[15] See AR5 WGII, figure 13.4.

Figure 27

Key risks from climate change for poor people and their livelihoods and the potential for risk reduction through adaptation



Source: The contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, table 13.2. The figure illustrates the key risks from climate change for poor people.

71. Ms. Purnamita Dasgupta made a presentation on **rural areas and human settlements**. She highlighted that almost 50 per cent of the world's population and 70 per cent of the developing world's poor live in rural areas. Poverty rates in rural areas are high but are falling sharply, except in sub-Saharan Africa. Multiple non-climate stressors of vulnerability affect rural areas. Owing to their low adaptive capacity, geographical location, and high dependence on natural resource based livelihoods and agriculture, climate-related impacts on rural communities in developing countries are projected to be more significant than in developed countries. Evidence of such impacts already exists, including with regard to water access, food security and agricultural production. Rural areas in developing countries are also subject to secondary impacts and trade-offs between mitigation and adaptation policy affecting rural livelihoods, such as that on biofuels and on reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+) (see the discussion on biofuels in paras. 83, 108 and 115 below).

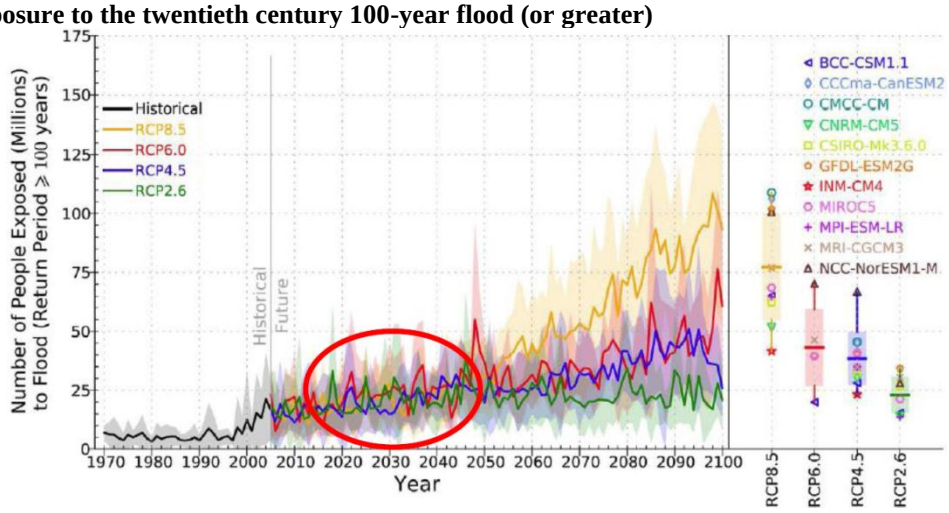
72. Ms. Dasgupta drew a distinction between **two types of adaptation** interventions: one that relates to **access** to credit, land, water, technology, markets, knowledge and information; and the other that relates to **perceptions** regarding the need for change in terms of relative neglect, lack of voice or lack of information.

73. She then discussed the different scales at which the **interaction of hazards, vulnerabilities and adaptation takes place in rural and urban areas**, focusing on the risk of drought and water shortage in rural areas, and of inland and coastal flooding in urban areas. While noting that climate change impacts rural and urban areas in different ways, she drew attention to **rural–urban interactions**, in particular how climate change stressors can exacerbate rural–urban conflicts related to the management of natural resources. Sectoral interactions also exist; for example, irrigation increases climate resilience for food and fibre production, but reduces water availability for other uses, such as energy production.

74. Ms. Dasgupta underlined that the **differential impacts of climate change** across people, countries and time **lead to situations of trade-offs and synergies**, creating challenges for a comparison of values. In this context, economic valuation of impacts and adaptation costs are key inputs for decision-making. However, costing challenges exist when evaluating non-market goods and services that cannot be monetized, especially where communities and economies are directly dependent on ecosystem services. It is possible to follow a multi-metric approach that uses a mix of quantifiable and non-quantifiable costs, and monetary and non-monetary metrics (e.g. declining calorie consumption per capita). However, considerable challenges remain in relation to distributional impacts and uncertainty.

75. Ms. Dasgupta concluded that a variety of interventions are effective for **adaptation in human settlements**, including incentives, regulation and instruments, and underlined the role of the public sector in removing institutional barriers, providing basic public health and amenities and protecting biodiversity.

Figure 28
Global exposure to the twentieth century 100-year flood (or greater)



Source: The contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure 3.6. The figure shows the number of people exposed to floods under historical and future scenarios of climate change.
Note: The abbreviations on the right-hand side of the figure identify the models used (see figure 3.6 for details).
Abbreviations: RCP = representative concentration pathway;

76. Ms. Balgis Osman-Elasha made a presentation on **adaptation options, needs, opportunities and associated costs**. She noted that the framing of adaptation has moved from a focus on biophysical vulnerability to the wider social and economic drivers of vulnerability and people's ability to respond. The **definition of adaptation** in AR5 is slightly different from that used in AR4, as it distinguishes more explicitly between human and natural systems. In human systems, adaptation seeks to moderate harm or exploit beneficial opportunities, while in natural systems, human intervention may at best facilitate adjustment to expected climate change and its effects. The theory and the evidence indicate that, in general, adaptation cannot overcome all climate change effects.

77. Regarding **adaptation needs**, Ms. Osman-Elasha explained that they arise when the anticipated risks or experienced impacts of climate change require action to ensure the safety of populations and the security of assets, including ecosystems and their services. The concept of 'needs' has evolved from national adaptation programmes of action (NAPAs), where needs were identified as priority adaptation activities, and the focus has shifted from biophysical vulnerability to a focus on the wider social and economic drivers of vulnerability and people's ability to respond. The AR5 introduces an iterative risk management framework for adaptation, which includes a long-term practice of assessing and reassessing the effectiveness of past decisions within a continuous learning process (figure 29).

78. She grouped **adaptation options**, which refer to the strategies and measures available to address needs, into three categories: structure/physical; social; and institutional. The AR5 emphasizes the role of institutional options for identifying, developing and pursuing climate-resilient pathways, as well as technological innovation and integration of adaptation development planning. Many of the technological and engineering options are still the most commonly used strategies, but there is growing recognition of the value of ecosystem-based adaptation. The options for addressing needs in ocean systems are still poorly developed. AR5 WGII outlines the opportunities, constraints and limits to adaptation in different sectors and regions.[16]

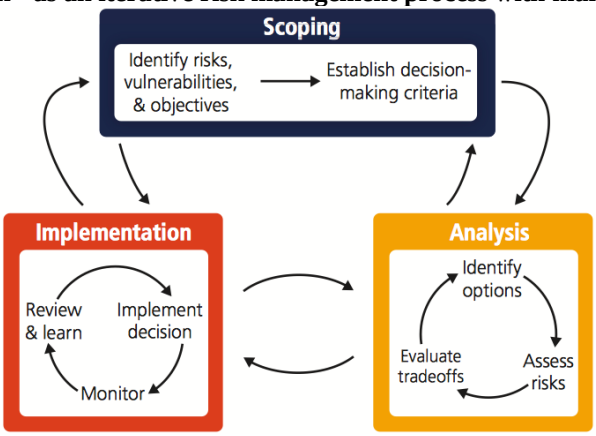
79. On the issue of **costing adaptation**, she underlined that global adaptation cost estimates are greater than current adaptation funding and investments, particularly in developing countries, thereby suggesting a funding

[16] See the AR5 WGII, table 16.3.

gap and a growing adaptation deficit. The World Bank estimates that the global need for adaptation funds is in the range of USD 70–100 billion per annum, with actual expenditures estimated at USD 244 million in 2011 and at USD 395 million in 2012. She noted that a variety of approaches were used to calculate the estimates, generating considerable uncertainty regarding the full range.

80. In concluding, Ms. Osman-Elasha stressed that: adaptation assessments have demonstrably led to a general awareness among decision makers and stakeholders of climate risks and adaptation needs and options, but that this has often not translated into adaptation action; adaptation generally needs to be seen within the framework of the overall development pathway of the country, particularly for developing countries; opportunities exist to enable adaptation planning and implementation for actors across all sectors and geographic regions; and successful adaptation requires not only identifying adaptation options and assessing their costs and benefits, but also exploiting available mechanisms to expand the adaptive capacity of human and natural systems.

Figure 29
Climate-change adaptation - as an iterative risk management process with multiple feedbacks



Source: Summary for policymakers in the contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.3. The figure shows adaptation understood as part of an iterative risk management process.

81. Ms. Asuncion Lera St. Clair made a presentation on **climate-resilient pathways** and the relationship between adaptation, mitigation and sustainable development. Regarding the informational basis used by AR5 WGII, she pointed to a large increase in the literature on climate change and especially on adaptation, enabling a clearer view of the risks posed by climate change. She also noted an enhanced knowledge of the interactions among adaptation, mitigation and sustainable development. Such a holistic, integrated perspective grounded in an extensive, multidimensional set of research results provides the informational basis for analysing risks and options for solutions; identifying links among adaptation, mitigation and sustainable development; and making decisions and choices.

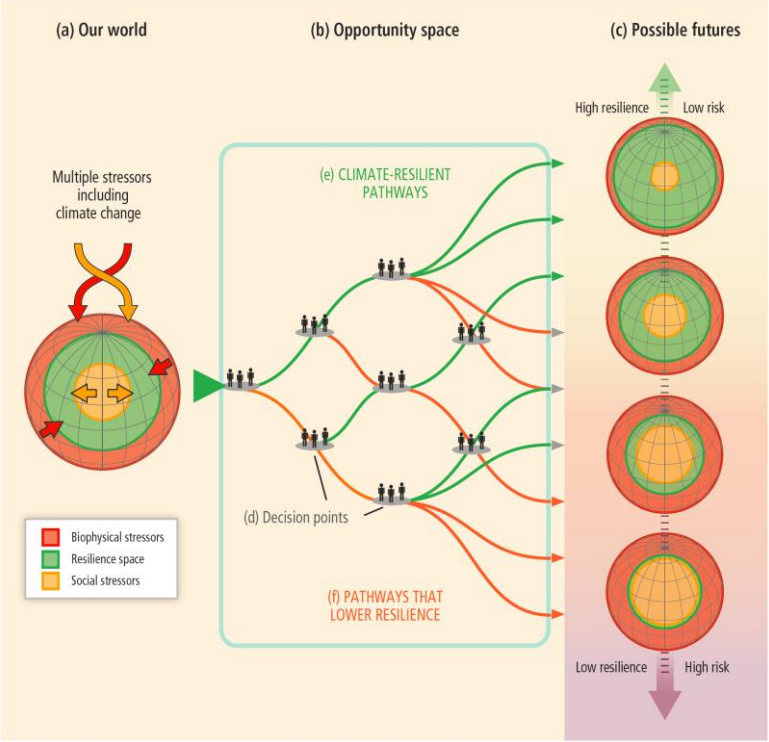
82. Underlining that adaptation as an isolated set of actions may have limited consequences because of the multiple interactions between human and natural systems, Ms. Lera St. Clair stressed that: **adaptation and mitigation are interdependent**; they can both reduce climate risks but do so according to different timescales; adaptation addresses current and committed climate change; mitigation reduces future climate risks; and **adaptation and mitigation choices in the near term will affect the risks of climate change throughout the twenty-first century**.

83. On the issue of **risks and trade-offs between adaptation and mitigation**, she stated that the integration of mitigation and adaptation responses can generate mutual benefits and co-benefits with sustainable development, but may also lead to negative consequences if choices are not carefully analysed, pointing to the example of land use for biofuels or food, or REDD+ programmes that lead to livelihood losses (see para. 115 below). She added that while climate change poses a moderate threat to current sustainable development in general, there are cases of residual damage and limits to adaptation. **In the future, climate change will pose a severe threat to sustainable development**.

84. She described **climate-resilient pathways** as development trajectories that combine mitigation and adaptation to realize the goal of sustainable development and help to avoid "dangerous interference with the climate system". Climate-resilient pathways include actions to ensure that effective risk management and adaptation can be implemented and sustained while avoiding negative consequences from trade-offs. While recognizing that effective adaptation strategies that are linked with development and have mitigation co-benefits can help to reduce vulnerability, she underscored the need for more research on the benefits, synergies, trade-offs and limitations of major mitigation and adaptation options, along with their implications for sustainable and equitable development.

85. Ms. Lera St. Clair highlighted that **the prospects for climate-resilient pathways are fundamentally related to progress on climate change mitigation**, while stressing that both mitigation and adaptation are essential for climate risk management at all levels. Delayed action reduces the number of options for the future because high emission pathways will reduce future options for climate-resilient pathways as adaptation limits are reached. To promote sustainable development within the context of climate change, climate-resilient pathways may involve significant transformations in political, economic and sociotechnical systems. These transformations, which have ethical and equity dimensions, may be reactive, forced or induced, as well as deliberatively created through social and political processes.

Figure 30
Opportunity space and climate-resilient pathways



Source: Summary for policymakers in the contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.9. The figure demonstrates that climate-resilient pathways offer some flexibility, yet depend on past decisions, which can significantly reduce or enhance future potentials.

86. In concluding, she noted that the expanded scientific focus of AR5 WGII, combined with increased practice and experience with adaptation, as well as with synergies with mitigation and development, creates opportunities for evaluating policy options and their risks in the search for climate-resilient development pathways. The opportunities show that there is still time in which to avoid the catastrophic effect of climate change, and that various decision points and pathways that lead to a more resilient world exist (figure 30).

2. General discussion

87. The discussion was guided by the following guiding questions:

(a) What does AR5 WGII tell us about the overall progress on adaptation made thus far and the projected progress in view of the long-term global goal?

(b) Are the existing adaptation activities adequate and effective, particularly in terms of the support provided to developing countries?

(c) What are the adaptation costs associated with various mitigation pathways as defined by their degree of global mean warming?

(d) What are the adaptation options, needs, opportunities and costs associated with the projected risks?

(e) What are the differences in terms of adaptation options, needs, opportunities and costs between various groups of people as determined by their livelihoods, poverty and development level?

(f) What types of adaptation are the most promising to cope with the various climate change risks?

(g) What is the relationship between the key climate risks and various levels of global temperature rise in the long term, including the possible impacts beyond 2100? How can this be factored into policymaking under the Convention?

88. As regards the **adaptation funding gap** in developing countries, a Party mentioned that the costs of adaptation could be higher in those countries due to, inter alia, the economic situation, the large population and socioeconomic aspects. The experts answered that many of the studies on adaptation costs, including a study by the World Bank,[17] focus on developing countries, and that the findings on adaptation costs were not included in the AR5 WGII summary for policymakers because of the wide range of figures.

89. Responding to a question on whether the estimates of **adaptation costs** were calculated in the light of developing countries' needs or the funding available, and in response to a comment on the discrepancy between the actual costs of adaptation and the costs estimated by some models, an expert answered that adaptation costs are typically estimated based on needs rather than on available or spent funds. Another expert added that the aggregated costs of adaptation, estimated using a top-down approach and not by sector, are uncertain and the estimates differ, not least because of the discrepancy between needs and actual expenditures (with expenditures being in the order of one per cent of the needs), mentioning the specific estimates calculated in a World Bank study (see para. 79 above). Another expert explained that the costs of adaptation and of climate change need to be clearly distinguished. The former is calculated using evidence from foreign domestic aid, such as NAPAs and non-governmental studies. The latter is related to loss and damage, which is difficult to capture with economic models, in particular because models use damage functions that are incapable of capturing the reality, poorly represent extreme events, and use only a percentage of gross domestic product (GDP), meaning that model-based estimates are most likely to provide only a lower indication of actual adaptation costs. The experts further commented that some adaptation costs, such as loss of place or culture are difficult to monetize; that costs differ significantly between studies owing to the assumptions used and as a result of the limitations arising from uncertain or incomplete damage functions; that externality costs or ancillary costs are not included in the cost estimate; and that there is a need for additional information, including on the costs of adaptation by sector, and actual data rather than estimated data.

90. One Party commented that **costs will depend on the definition of "adaptation"**, noting the difficulty in distinguishing between adaptation and general development flows, and asked if the differences between the cost estimates of various studies may be due to the different definitions used for "adaptation". An expert responded that the World Bank launched a study to track adaptation versus development financing,[18] and that if the methodology proposed in the study is used, more reliable adaptation costs could be generated. Another expert added that further difficulties exist when costing adaptation, since mitigation and adaptation are also linked through the fact that mitigation helps to reduce the costs of adaptation.

[17] World Bank. *Economics of Adaptation to Climate Change*. *Synthesis report*. Available at <http://documents.worldbank.org/curated/en/2010/01/16436675/economics-adaptation-climate-change-synthesis-report>.

[18] World Bank. *Monitoring Climate Finance and ODA*. Available at <http://siteresources.worldbank.org/ENVIRONMENT/Resources/DevCC3_Monitoring.pdf>.

91. One Party noted that **adaptation costs are not limited to developing countries**, stressing that in his country over 150 climate-related events had been recorded since 1980, with concomitant adaptation costs exceeding USD 1 billion (total adaptation costs exceeding USD 1 trillion). He requested clarification regarding the **uncertainties and limitations associated with top-down estimates of global adaptation costs**. An expert responded that opportunities for capitalizing on adaptation needs vary by country in both developed and developing regions, and that he could not explain why so many assessments focus on developing countries. He added that the cost uncertainties are due to the use of different models and impacts, as the models do not cover all sectors, especially human livelihoods and ecosystem protection. AR5 WGII therefore provided limited evidence, indicating a medium confidence level in relation to these costs.

92. Regarding **methodologies to quantify the adaptation benefit** of various options, an expert explained that the majority of the approaches in the literature examined benchmarks of desired adaptive capacity and measured the level of deviation from the benchmarks for specific sectors, interventions (e.g. sea level rise) and global goals, although no standardized methodologies exist to quantify these benefits. The same observation applies to costing adaptation, which typically focuses on what can be quantified, rather than on the ancillary or externality costs which tend to be excluded (see para. 89 above). Another expert commented that multiple overlapping methodologies, each focusing on one particular aspect only, have the benefit of providing overviews, but that no single methodology exists to cover all aspects as some adaptation benefits are not quantifiable. This is comparable to the fact that no methodology exists to quantify the overall benefits of development.

93. Responding to a question on **what is included in the portfolio of adaptation activities**, an expert indicated that AR5 WGII calls for adaptation to be addressed within the local context and that, in many cases, adaptation opportunities could arise in actions that may be different from traditional concepts of adaptation.

94. One Party requested clarification regarding the global amount of **investment in adaptation, the bodies investing** in adaptation and the attractive options for investment. Another Party asked why **investment in adaptation is seen as unattractive** in comparison with mitigation, as these investments could build reliance, for example in infrastructure, and should be seen as an opportunity, not as a cost. In response, an expert said that WGII concluded that there are attractive, synergistic opportunities for adaptation investment, especially in the context of the co-benefits with mitigation and sustainable development. He added that the world is moving into an era in which such investment opportunities can be created to address adaptation, mitigation and sustainable development needs. Another expert referred to the opportunities for adaptation identified in table 16.3 of AR5 WGII.

95. A Party commented on the **lack of communication between the Financial Mechanism under the Convention** (e.g. the Green Climate Fund) **and scientists** (e.g. the IPCC). He asked **how governments can carry out options identified in the UNFCCC process**, and how the IPCC could advise urban areas, communities and governments that are engaging in a non-climate-resilient development pathway. An expert underlined that, in order to move towards proactive adaptation, progress needs to be achieved as regards: the perception by policymakers and stakeholders that there is a risk; assessment of that risk; recognition that the risk needs to be acted upon and that the investment needed to respond thereto is justified; and capitalization on the opportunities for adaptation.

96. On the issue of the **difference between risk levels at 1.5 °C and 2 °C limits**, an expert answered that relatively few studies have explicitly considered the 1.5 °C limit, and that most of the adaptation literature does not generally identify a specific risk level for a specific temperature. In response to a follow-up question suggesting that more emphasis should be given to the 1.5 °C limit in the assessment process, an expert reiterated that all available literature on this temperature limit was considered in AR5 WGII. He added that risk-framing enables the analysis of a wide range of motivations for setting a target at various levels.

97. Some Parties commented that immediate emission reductions are required to reach low-stabilization pathways, illustrating that mitigation is the key to **avoiding dangerous anthropogenic interferences**; others pointed out the need for discussion regarding safe levels of impacts to achieve the objective of the Convention. An expert commented that if mitigation action is delayed, the opportunities to stay below the 2 °C limit will disappear. She added that the IPCC may not determine the 'safe' or 'dangerous' level, as this value judgment will be made by governments based on their perspectives of what is 'safe', for whom, for what, and according to which time frame. Another expert said that recognition of the associated safety issues was required, which

depends on the scale, frequency and severity of the impact, since the widespread consequences of climate change have already been witnessed. For example, from the perspective of a species, human individual or village that is currently facing those impacts, it has already reached an unsafe level. This shows the need to recognize that there is no 'guardrail' below which there are no impacts and that a more nuanced view should instead be fostered.

98. Regarding **pathways linking mitigation and adaptation**, a Party noted that mitigation can reduce adaptation needs, although the issue of quantification of adaptation benefits remains. Another Party said that prospects for climate-resilient pathways are fundamentally related to progress on mitigation, adding that poverty often prevents transition towards climate-resilient pathways. An expert noted that although mitigation is of benefit to adaptation, it cannot be quantified. Therefore, in implementing actions to address climate change, a holistic perspective should be used, together with an iterative risk management process and learning by doing, seeking 'no regrets' options, synergies and co-benefits, with a focus on those who are most vulnerable.

99. A Party commented that, according to figure 22, the **levels of additional risks for unique and threatened systems and due to extreme weather events are already moderate at 1 °C**. Noting that, for example, early warning systems and multipurpose-resistant houses could minimize loss of life, he asked for guidance to set policy priorities aimed at improving the resilience of the most affected people (e.g. minimizing the loss of life versus livelihoods versus ecosystem services). An expert responded that AR5 WGII identifies risks, and that policy priorities should be set by policymakers. Another expert replied that the establishment of early warning systems is a productive method only when used in an appropriate manner by combining knowledge and action, but will be ineffective if these two elements are not combined in a fair and just way.

100. Several questions arose regarding the definition of "**climate resilience"** and "**climate-resilient pathways"**,[19] the difference between **"resilient" and "sustainable" development**, the extent to which a level of resilience can be seen as a target, and the likelihood of attaining sustainable development with the existing adaptation opportunities. As regards the ability to attain sustainable development, an expert said that this depends on the decisions to be made by policymakers. Regarding the difference between "resilient" and "sustainable" development, an expert explained that sustainable development includes "development" and has historically featured a strong economic component, while "resilience" is more independent from development – it can be related to development, but in a more flexible way. One Party commented that, before aiming for sustainable development, resilience must be built. Another expert underlined that the term "resilience" implies multiple synergies among approaches identified in the 'solution space' (figure 20) and has moved from natural sciences to social sciences. One expert emphasized that the scientific community is divided on this term, since its use varies from specific meanings in some disciplines, such as in ecology, to very vague interpretations in others. Further, in social sciences, "resilience" often focuses on the normative outcome of being resilient, thereby running the risk of masking the important process of actually reaching that desirable outcome.

101. Several questions were related to **international cooperation** on the transfer of technologies for adaptation to developing countries and adaptation in general. Experts stressed that while technology transfer is needed for some modern agricultural work, many low-cost, simple, efficient adaptation technologies are available, such as water-harvesting technology or clean cook stoves in rural households. Such technologies are not being fully deployed due to social, political and economic constraints, rather than due to technology transfer issues (see para. 106 below). Further, the role of social, political and organizational aspects should no longer be underestimated and should be appropriately addressed. In response to a follow-up question regarding how national adaptation planning could address some of these challenges, for instance in remote rural areas, an expert clarified that social and political aspects should be included in the national planning process in order to obtain a broader perspective of the risks, options and opportunities.

102. One Party asked for clarification regarding the **areas and issues that Parties should focus on in the context of international cooperation for adaptation** and the provision of means of implementation. An expert replied that this question relates more to the political, rather than the scientific, arena. Another expert underlined the importance of considering cooperation while bearing in mind the linkages among adaptation, mitigation and

[19] Climate-resilient pathways are sustainable-development trajectories that combine adaptation and mitigation to reduce climate change and its impacts. They include iterative processes to ensure that effective risk management can be implemented and sustained (summary for policymakers in the contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, page 28, section C.2).

sustainable development. She further noted several overlapping approaches for managing the risks of climate change, including by reducing vulnerability and exposure, adaptation (incremental and transformational) and transformation approaches (see table SPM.1). International cooperation is involved in many of these approaches (see para. 28 above).

103. Responding to a question on the **risks related to rural–urban interaction and the urbanization process** taking place in developing countries, an expert answered that this process will exacerbate risks such as a high mortality rate, injuries or loss of infrastructure, mainly due to the high population density resulting from urbanization and gaps in infrastructure. The disruption of an integrated service provision would affect larger areas and populations.

104. As regards the differences between **climate-smart and climate-resilient agriculture**, an expert commented that, in the past, the focus was on sustainable smart agriculture and the creation of optimal conditions for crops, for example in terms of soil moisture, but that in a changing climate optimal conditions can no longer be created. Thus, the main challenge for climate-smart agriculture is to become more resilient by using crops that can perform under suboptimal conditions, such as heat stress and drought. One Party asked about means of raising awareness of existing climate-smart agricultural technologies in rural settlements. An expert answered that adaptation planning should not be limited to technologies and infrastructure, but should also encompass social, political and institutional aspects if risks and opportunities are to be fully understood (see para. 101 above).

105. Regarding adaptation options to deal with **sea level rise**, including migration, one expert noted that the scale of what is currently perceived as adaptation may change in the long term following a sea level rise of many metres. Another expert responded that, today, one in eight people is mobile. People make mobility choices (ranging from voluntary mobility to forced relocation), taking into account food security, employment opportunities, livelihood security, and physical (natural) or conflict safety. One concern identified in AR5 WGII is that people are moving due to food security and climate-sensitive livelihoods. While most movements are currently internal, as the impacts of climate change unfold these could lead to undesirable displacement or relocation. Concerns are greater in areas with geographical constraints such as small islands. She underlined that, currently, four times as many people are displaced by extreme weather events and earthquakes than by conflicts.

106. On the issue of **key barriers to adaptation on the ground**, **and elements required to conduct better adaptation assessments and adaptation planning**, an expert noted that there is a lack of awareness and of communication among various ministries and a misunderstanding of risks, with some pointing to technology aspects and others drawing attention to social, political and institutional issues. At the same time, farmers, other local stakeholders and indigenous people often have a different understanding of risks at the local level. Another expert pointed to the considerable challenges involved in taking into account the wide range of factors determining risk in a system. As multiple stressors are involved, all of which may interact, they are likely to create circumstances that are very difficult to predict, regardless of the level of ambition of the research conducted. **Decision-making under uncertainty is therefore the primary mode of action for the foreseeable future**. Yet another expert underlined that while some constraints to adaptation need to be overcome both in developed and in developing countries, it should be recognized that in developing regions climate change is not the only pressing need. In the developed world, there is a greater focus on mainstreaming adaptation in national planning and awareness-raising, but fewer actions are focused on implementation. Another expert underlined that while engineering and technological adaptation options are the most commonly used, the importance of other types of adaptation, such as ecosystem-based behavioural changes or diversification of livelihoods, needs to be recognized.

107. In response to a question on examples of policies and measures that have successfully addressed **non-climatic stressors** and how inadequate planning can lead to maladaptation, an expert answered that climate is indirectly, rather than directly, linked to a number of risks, such as food insecurity or water competition, but that these interactions are difficult to assess. She illustrated how, in a multiple causal chain, climate change could exacerbate food production issues and lead to price shocks, and how adaptation measures could vary from food imports to food aid. Another expert noted that additional climate stressors may lead to the disappearance of landraces in agriculture, and thus reduce the number of adaptation options, as well as to increased vulnerability of deltas around cities. He added that there are many such confounding factors and alluded to the examples of water competition being problematic only for those consumers without a water tap or for poor people who are

pushed into areas with higher exposure to climatic impacts. He emphasized that all such phenomena could nevertheless be clearly connected to climate change.

108. Some Parties asked about the **positive and negative impacts of mitigation policies at the local level and the scope of the assessment of biofuels**. An expert clarified that literature in four areas was assessed to identify the implications for livelihoods of implementing mitigation policies (e.g. the clean development mechanism (CDM), REDD+, the voluntary carbon market, and the biofuels policy and its impact on other countries in terms of indirect land-use change). He distinguished between two types of literature assessed: one that focuses on the effectiveness of GHG emission reductions; and the other that focuses on the effect of these reductions on the poor, pointing to the threats posed by REDD+ to indigenous peoples and people who rely on protected forest areas. He further noted that voluntary carbon markets do not take into account local benefits, except for Gold Standard projects; extensive literature exists on the positive and negative effects of biofuel development from a poverty alleviation point of view; and that each of the four above-mentioned policies has proved to be a strong mechanism for global mitigation, but that few mechanisms have created benefits at the local level or in terms of poverty alleviation (see paras. 71 and 83 above and 115 below).

D. Part 3: setting the scene for the consideration of the contribution of Working Group III to the Fifth Assessment Report

1. Presentation by an expert

109. Part 3 of the meeting opened with a scene-setting presentation by Mr. Ottmar Edenhofer, Co-Chair of IPCC Working Group III (WGIII), on the overarching findings and new approaches of AR5 WGIII relevant to the two themes of the 2013–2015 review. He explained that WGIII explored the full 'solution space' in order to inform decision makers on the various possible emission pathways, their underlying costs, risks and opportunities.

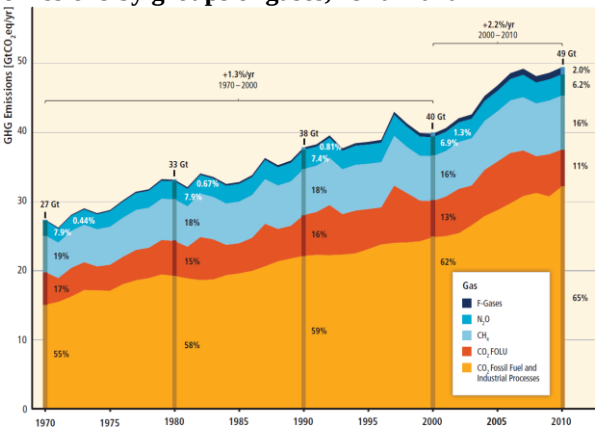
110. On the issue of **trends in stocks and flows of GHG emissions**, Mr. Edenhofer stressed that GHG emissions growth has accelerated despite mitigation efforts and the global economic crisis, and that emissions growth between 2000 and 2010 was greater than in any of the previous three decades (figure 31). Regarding the historical perspectives of anthropogenic GHG emissions, he noted that about half of the cumulative anthropogenic CO_2 emissions between 1750 and 2010 occurred in the last 40 years (figure 32). He underlined that, for the first time, the IPCC presented the underlying uncertainties in the estimated historical emissions in more detail.

111. With respect to **regional patterns of GHG emissions**, Mr. Edenhofer explained that these patterns are shifting along with structural changes in the world economy. Upper middle-income countries are replicating the emissions trajectories of upper-income countries, and the industrial and energy sectors play the most important part in the increase in emissions. The land-use sector is not as significant in high- and middle-income countries as in low-income countries, where it is the main emission source (figure 33).[20] Income is the most important driver of GHG emissions at the global level, followed by population growth. Emission growth driven by these two factors has overtaken emission reductions from improvements in energy efficiency. The long-lasting trend in gradual decarbonization has been reversed during the last decade, mainly owing to an increased use of coal in the power sector (figure 34).

[20] The *structure* and dynamic of [emissions] data for the upper middle-income group indicates limited leapfrogging (see para. 183 above).

Figure 31

Total annual anthropogenic greenhouse gas emissions by groups of gases, 1970–2010

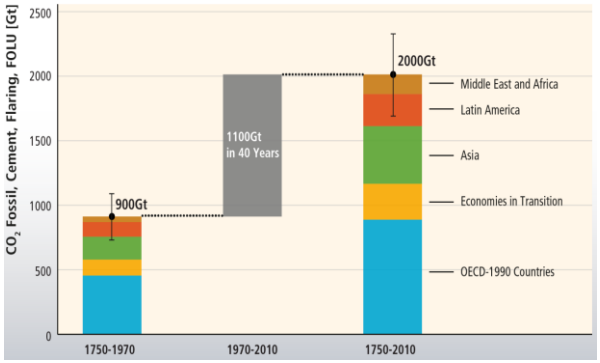


Source: Summary for policymakers in the contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.1. The figure illustrates that emission growth has accelerated in the last decade.

Abbreviation: FOLU = forestry and other land use.

Figure 32

Cumulative anthropogenic CO_2 emissions between 1750 and 2010



Source: Simplified version of figure TS.2 from the technical summary in the contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (see slide 7 of the presentation by Mr. Ottmar Edenhofer (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_edenhofer_sbsta_sed_wg3_overview.pdf>. The figure illustrates the historical cumulative anthropogenic CO_2 emissions per region and group of countries between 1970 and 2010.

Abbreviation: FOLU = forestry and other land use.

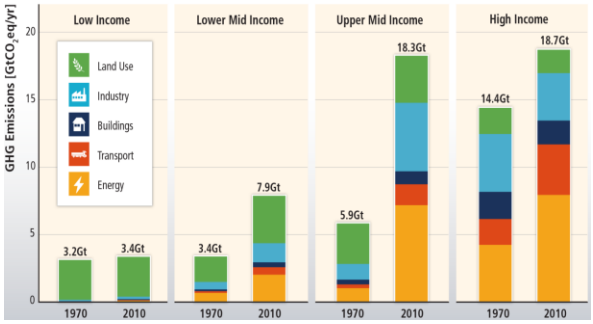
112. Regarding the **action required to limit warming to 2 °C**, Mr. Edenhofer underscored the substantial technological, economic and institutional requirements, in particular in the energy sector and potentially in land use. Without additional mitigation, the global mean surface temperature is projected to increase by 3.7–4.8 °C over the course of the twenty-first century (based on median transient climate response estimate; the range (90% percentile) is 2.5°C to 7.8°C when adding climate uncertainty). The stabilization of anthropogenic concentrations at low levels requires a move away from the baseline, regardless of the global mitigation goal. Even a 3 °C limit requires a substantial reduction in GHG emissions and a fundamental transformation of the energy system. A 2 °C limit requires a larger emissions reduction in the short to medium term, and negative emissions in the second half of the twenty-first century. Both require substantial scaling-up of low-carbon energy. Important aspects of risks of mitigation are therefore associated with the scaling-up of low-carbon technologies (approximately 300 per cent above current levels by 2050 for a 2 °C limit).

113. **Delaying mitigation** increases the difficulty and narrows the options for limiting warming to 2 °C. Immediate mitigation action, which is consistent with a cost-effective emissions pathway to achieve the 2 °C target, would imply a reduction in emissions of about 3 per cent annually between 2030 and 2050, an unprecedented emission reduction rate in economic history. On the other hand, delaying action would imply even larger emission reductions in the future (about 6 per cent per year between 2030 and 2050), at higher costs and with higher risks (figure 36). Mr. Edenhofer added that the current Cancun pledges are insufficient to achieve the long-term global goal.

114. With regard to **the 1.5 °C target**, scientific evidence remains limited because of the limited number of studies on this limit for global warming and the absence of multi-model comparison studies that analyze the relevant pathways more systematically. Available scenarios in these existing studies are characterized by a temperature overshoot and large-scale application of CO_2 removal technologies; immediate mitigation action; a rapid scaling-up of the full set of technologies; and development along a low-energy demand pathway.

Figure 33

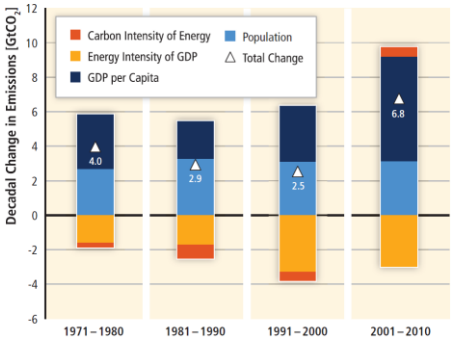
Greenhouse gas emissions by country group and economic sector



Source: Slide 8 of the presentation by Mr. Ottmar Edenhofer (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_edenhofer_sbsta_sed_wg3_overview.pdf>.

Figure 34

Decomposition of the change in total global CO_2 emissions from fossil-fuel combustion



Source: Summary for policymakers in the contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.3.

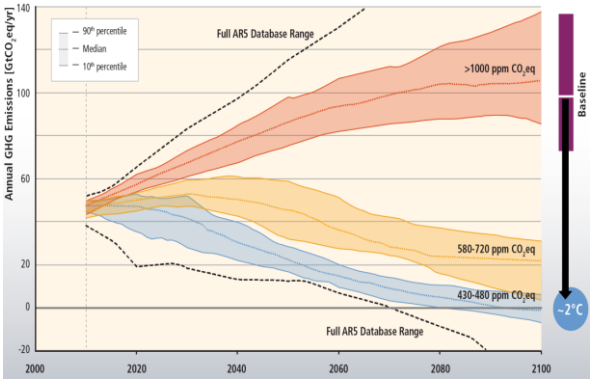
Abbreviation: GDP = gross domestic product.

115. Regarding **mitigation costs**, Mr. Edenhofer noted that available estimates vary widely, but do not significantly affect global GDP growth. He explained that the uncertainties surrounding the global cost estimates are due to the wide range of mitigation costs, which are partially due to the differences in projected low-carbon technology uptake in the various models. While underlining that global costs rise with the level of ambition of the mitigation goal, he pointed out that mitigation action would delay, but not sacrifice, economic growth. Mitigation consistent with the 2° C limit involves annualized reduction in consumption growth of 0.04 to 0.14 (median: 0.06) percentage points over the century relative to annualized consumption growth from the baseline that is between 1.6 and 3 per cent per year. He added that the availability of technologies seriously affects mitigation costs. Without carbon dioxide capture and storage (CCS) and with limited availability of bioenergy, the mitigation costs would increase markedly in the medium term. Specifically, if CCS is unavailable, the costs of staying below the 2 °C limit (with a larger than 50 per cent chance) will increase by approximately 140 per cent relative to default technology assumptions, and if bioenergy is limited, the costs will increase by approximately 70 per cent. The combination of bioenergy and CCS (BECCS) in the models is also important for negative emissions to be achieved in the second half of the twenty-first century (figure 37) (see paras. 71, 83 and 108 above). Projections in many models could not stay below 2 °C by 2100 if additional mitigation is considerably delayed or if the availability of key technologies, such as bioenergy, CCS, and their combination (BECCS), is limited.

116. On the issue of **options to reduce GHG emissions**, he emphasized that mitigation scenarios indicate the necessity to fully decarbonize energy, but that there is flexibility in that process. The scale of energy demand reductions is important as it will determine the level of flexibility in decarbonizing energy supply and the associated ability to hedge against supply-side risks, avoid infrastructure lock-in, and determine the co-benefits of mitigation. Regarding **mitigation co-benefits**, he pointed to positive side effects of mitigation, in particular for human health, but also for other societal goals. For example, low stabilization scenarios carry substantial health benefits through reductions of emissions of black carbon. At the same time he explained the difficulty of translating such co-benefits into net welfare gains (figure 38).

Figure 35

Greenhouse gas emission pathways, 2000–2100: scenarios from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

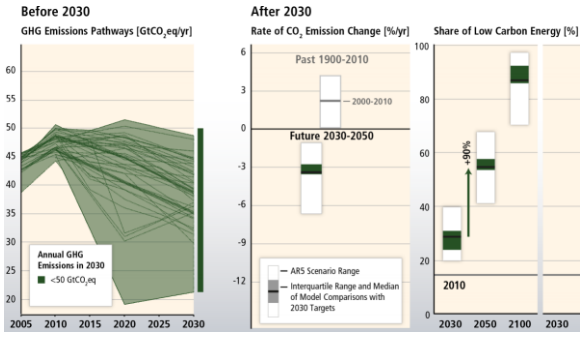


Source: Slide 16 of the presentation by Mr. Ottmar Edenhofer (Intergovernmental Panel on Climate Change (IPCC)), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_edenhofer_sbsta_sed_wg3_overview.pdf>. The figure shows some emission pathway scenarios as used in the IPCC Fifth Assessment Report.

Abbreviations: CO_2 eq = CO_2 equivalent, AR5 = Fifth Assessment Report of IPCC

Figure 36

The implications of greenhouse gas emission levels in 2030 for the rate of CO_2 emission reductions and scaling-up of low-carbon energy (mitigation scenarios reaching about 450 to 500 ppm by 2100)



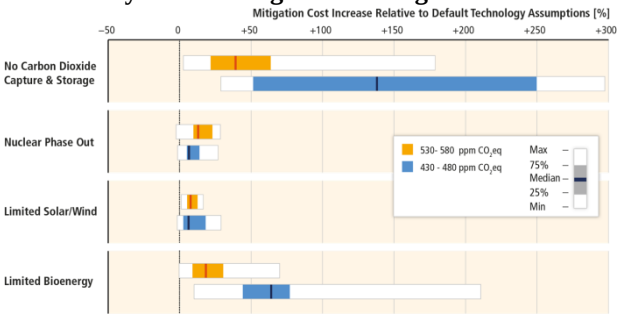
Source: Slide 20 of the presentation by Mr. Ottmar Edenhofer (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_edenhofer_sbsta_sed_wg3_overview.pdf>. The figure summarizes the near- and mid-term mitigation needed to limit greenhouse gas concentrations to between 450 and 500 ppm CO_2 eq by 2100.

Abbreviations: GHG = greenhouse gas, AR5 = Fifth Assessment Report of IPCC

117. With regard to **policies that have attracted the greatest interest,** Mr. Edenhofer underlined that all scenarios considered in AR5 WGIII identified the pricing of CO_2 as a necessary condition to achieving the long-term global goal, in conjunction with other policies. Substantial reductions in GHG emissions would require large changes in annual investment flows and in investment policies, which would lead to an adjustment of global investment in the energy sector (figure 55). Such policies would require a credible CO_2 price signal. While recognizing the increase in available literature since AR4 on policies designed to integrate multiple objectives, increase co-benefits and reduce adverse side effects (e.g. government provision of public goods and services, regulatory approaches, economic instruments and information programmes), he called for future research and ex-post evaluation of such policies that are already in place; and the provision of information to stakeholders on the appropriate way of combining the available policy instruments, so that they effectively complement each other.

Figure 37

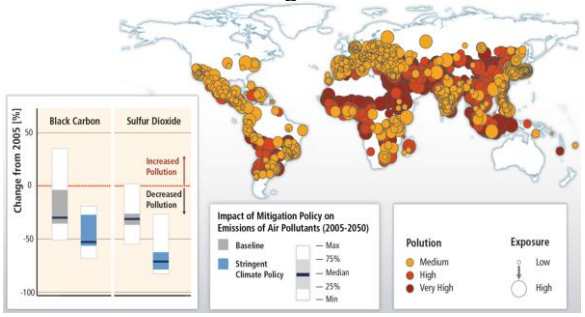
Availability of technologies and mitigation costs



Source: Slide 27 of the presentation by Mr. Ottmar Edenhofer (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_edenhofer_sbsta_sed_wg3_overview.pdf>. The figure shows the dependence of mitigation costs on some mitigation technologies.

Figure 38

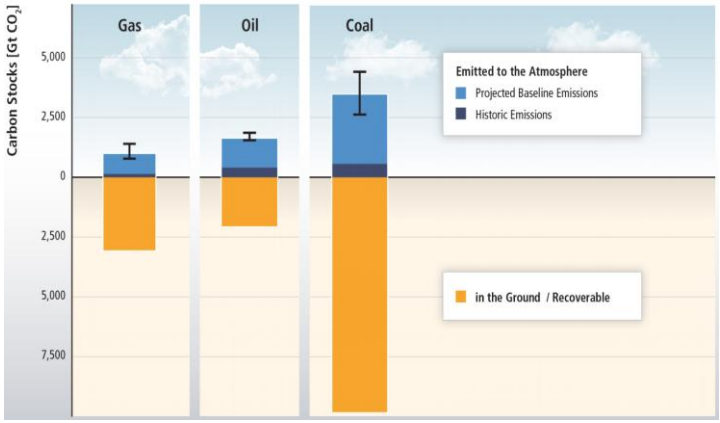
Health co-benefits of mitigation



Source: Slide 32 of the presentation by Mr. Ottmar Edenhofer (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_edenhofer_sbsta_sed_wg3_overview.pdf>. The figure illustrates some of the co-benefits of mitigation.

118. In concluding, Mr. Edenhofer stressed that **there is far more carbon in the ground than can be emitted, given the limited disposal space in the atmosphere**, which is why low-stabilization pathways are so demanding in terms of technological and institutional requirements (figure 39).

Figure 39
Levels of carbon in the ground and emitted for different types of fossil fuels



Source: Slide 41 of the presentation by Mr. Ottmar Edenhofer (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_edenhofer_sbsta_sed_wg3_overview.pdf>. The figure shows the amount of carbon that is estimated to be in the ground and the amount that has already been emitted to the atmosphere.

2. General discussion

119. The ensuing discussion was guided by the following questions:

(a) What does AR5 WGIII tell us about the mitigation action required to limit global warming to 2 °C or 1.5 °C, the relationship between mitigation and other climate change responses such as adaptation, and valuations, including expert value judgment?

(b) How reliable are the projections of emission pathways and how can they be used for decision-making at the global level?

(c) What are the options to reduce emissions through mitigation and low-carbon development?

120. A Party asked **how much CCS and bioenergy deployment could be performed at scale**, and if such an uptake is realistic in the long term. The expert explained that the WGIII findings on how much CCS, BECCS and bioenergy would be needed are based on the requirement in ambitious scenarios to have negative emissions in the second half of the twenty-first century to achieve low stabilization targets. He pointed to an appendix to the agriculture, forestry and other land use (AFOLU) chapter on bioenergy that highlights the diversity of opinions on this question and outlines the underlying risks of generating large amounts of bioenergy for food security and prices, as well as for biodiversity. He stressed the need for policymakers to consider the risks and benefits of using these technologies. The expert added that CCS and bioenergy are low-cost options for reducing emissions, but to reduce the associated risks, such options should be accompanied by an integrative institutional framework that would take into account the competition for land, notably a comprehensive carbon-pricing mechanism that covers all sectors, including land use.

121. Responding to a question raised by a Party regarding the **window of opportunity in relation to a 1.5 °C and 2 °C temperature rise**, the expert said that in AR5 WGIII this window is driven by the speed of the scaling-up of low-carbon technologies and the level of risk of such scaling-up, rather than by atmospheric physics, which is only the boundary condition. Scenarios consistent with a temperature rise of 1.5 °C combine all of the most ambitious features we know from the literature on the 2 °C limit. He added that mitigation action over the next decade will determine the required mitigation action after 2030 and its cost. The risk related to the scaling-up of low-carbon technologies becomes higher when mitigation is delayed. In response to a question on the additional risks that would be created by an overshoot in emissions and temperature, the expert said that overshoot is a typical feature of low stabilization scenarios, all of which therefore have risks.

122. Regarding the **global carbon budget**, a Party referred to figure 38 and asked how much CO_2 can still be emitted to achieve the long-term global goal. The expert indicated that the global carbon budget specified in AR5 WGIII is broadly consistent with that of AR5 WGI, but that a broader range of mitigation pathways have been considered in the former. He added that the limiting factor in the twenty-first century is not the availability of fossil fuels (figure 39), but rather the limited disposal space in the atmosphere, which is why climate change should be understood as a global common problem.

123. With respect to the **impact of mitigation on economic growth**, one Party asked how the reduction in consumption was calculated by the IPCC, in particular if the opportunities created by shifts in investments and the reduced spending on energy because of increased efficiency have been taken into account. The expert underlined that although climate mitigation can indeed be seen as an opportunity cost since it will reduce future consumption to some extent, it will also provide opportunities for new investments. He further explained that, for example, carbon pricing reduces return on investment in some sectors, and that, although the reallocation of budget creates opportunities in other sectors (figure 55), this reallocation comes at a cost. He added that two types of models exist: one that assumes the full utilization of all resources in the long term (i.e. without any idle resources and, consequently, with positive opportunity costs); and another where there are idle resources leading to smaller opportunity costs.

124. As regards the **total annual GHG emissions**, a Party asked if removals by sinks were included in the figures. The expert explained that land-use change, deforestation and afforestation were taken into account by the models, adding that in scenarios where CCS is not available, AFOLU becomes more important and more afforestation is needed.[21] Low stabilization pathways therefore depend not only on changes in energy supply, but also on changes in the AFOLU sector (figure 44).

125. Regarding the **use by the SED of information not included in the AR5 WGIII summary for policymakers** (SPM), several Parties opposed such use, in particular in relation to information on the categorization of countries based on income levels, and reminded participants that several countries also opposed the inclusion of this information in AR5 WGIII. They noted that the categorization of countries is not in line with the provisions of the Convention, and asked if such information is available in AR5 WGIII for Parties included in Annex I to the Convention and Parties not included in Annex I to the Convention. Other Parties welcomed the use of this information by the SED. The expert replied that deleted information from the SPM is available in the technical summary and underlying report, adding that the IPCC presents historical and factual data, such as cumulative, production-based and consumption-based emissions, from different perspectives, including according to income categories, so that policymakers can explore the issue from different perspectives.

126. On the issue of **metrics**, one Party commented that the global temperature potential (GTP) metric is better suited to carrying out an assessment of certain aspects of climate change only and asked about the importance of using GTP to guide mitigation policies, taking into account the fact that Parties have agreed on a temperature-related long-term global goal. The expert responded that global warming potential (GWP), GTP, and global damage potential were discussed by WGIII, and that GWP is "relatively robust", taking into consideration the fact that costs and mitigation strategies do not differ greatly if other metrics are used and the required data are available.

127. Regarding **fossil-fuel subsidies**, a Party asked about the emission reductions that would be achieved by their removal. The expert said the WGIII did not assess the impact of removing such subsidies, but stressed that it would require distinguishing between subsidy removal scenarios both with or without a carbon price.

[21] See the summary for policymakers in AR5 WGIII, figure SPM.7, available at <http://report.mitigation2014.org/spm/ipcc_wg3_ar5_summary-for-policymakers_approved.pdf>.

E. Part 3 – theme 1: the adequacy of the long-term global goal in the light of the ultimate objective of the Convention based on the contribution of Working Group III to the Fifth Assessment Report

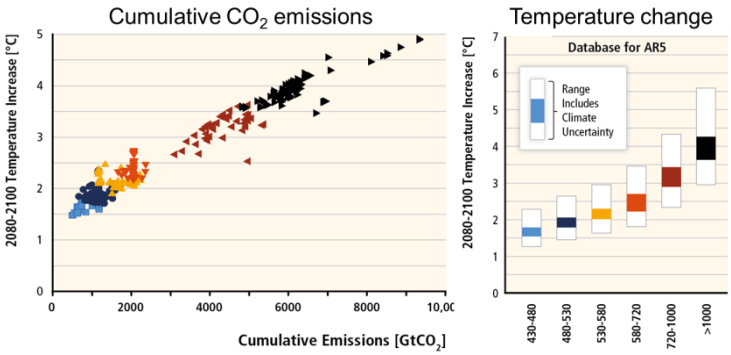
1. Presentations by experts

128. Mr. Volker Krey (IPCC) made a presentation on **transformation pathways and limiting warming to specific levels, notably a global mean warming of 2 °C or 1.5 °C relative to pre-industrial levels**. He explained that the WGIII experts collected approximately 1,200 scenarios from existing literature in an "AR5 scenario database" to assess transformation pathways, and their costs and mitigation implications. The scenarios were then categorized based on their CO_2 eq concentration in order to link them with the various RCPs assessed by WGI. Around 150–200 pathways corresponding to a concentration of 400 ppm CO_2 eq by 2100 are consistent with RCP2.6. While noting the wide range of scenarios, he said that their common element is the stringent emissions reduction required to limit warming below 2 °C.

129. Noting that, to achieve low levels of temperature change, cumulative CO_2 emissions must be limited, he indicated that the **emissions budget for staying below the 2 °C limit** is about 600–1,200 Gt CO_2 for the period 2011–2100, and historical emissions for the period 1870–2011 are about 1,850 Gt CO_2 (figure 40). Figure 40 also illustrates the range of temperature increase by the end of the twenty-first century for the six ranges of CO_2 eq concentrations used to categorize the scenarios in AR5 WGIII.

Figure 40

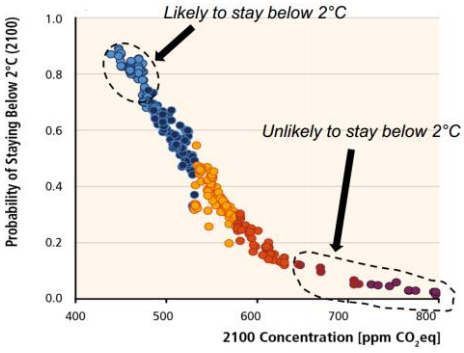
Relationship between cumulative CO_2 emissions and global temperature change



Source: Slide 5 of the presentation by Mr. Volker Krey (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2_krey_vuuren_sed3.pdf>. The figure illustrates how global warming is related to cumulative CO_2 emissions.

Figure 41

Probabilistic interpretation of the 2 °C warming scenarios



Source: Slide 6 of the presentation by Mr. Volker Krey (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2_krey_vuuren_sed3.pdf>. The figure shows the probability of staying below a 2°C limit as determined by atmospheric CO_2 eq concentrations.

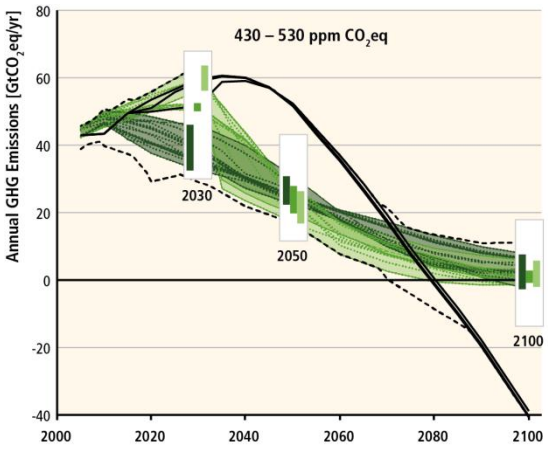
130. Mr. Krey underlined that a major advancement since AR4 is the probabilistic interpretation of the scenario literature, which shows the relationship between the atmospheric concentration of CO_2 eq in 2100 and the probability of staying under the 2 °C limit (figure 41). Scenarios in the lowest concentration category (430–480 ppm) have at least 66 per cent probability of staying below a 2 °C warming. For a concentration of 600 ppm CO_2 eq, which corresponds to the range of scenarios for RCP4.5, the likelihood of staying under the 2 °C limit is below 20 per cent. Therefore, to better cover the ranges of possible concentrations, two additional categories of scenarios were considered in AR5 WGIII in between RCP2.6 and RCP4.5, corresponding to concentrations ranging between 480–530 ppm (dark blue in the figure) and 530–580 ppm (yellow in the figure).

131. Regarding the **relationship between global GHG emissions and the likelihood of different temperature limits**, he showed how atmospheric concentration levels are linked to emission budgets and reductions (in 2050 and 2100), and the expert assessment of the likelihood of temperature change (see table SPM.1). Scenarios where atmospheric concentration levels of about 450 ppm CO_2 eq are reached by 2100, consistent with a likely probability of keeping temperature change below 2 °C, are characterized by emission

reductions of 40–70 per cent below 2010 levels by 2050 and by reductions of 80–120 per cent by the end of the twenty-first century. He stressed the interdependence between emission levels in 2050 and 2100 for scenarios in a given category due to the cumulative budget constraint – a high-end emissions level in 2050 would require a low-end emissions level in 2100 and the use of CO_2 reduction technologies such as BECCS.

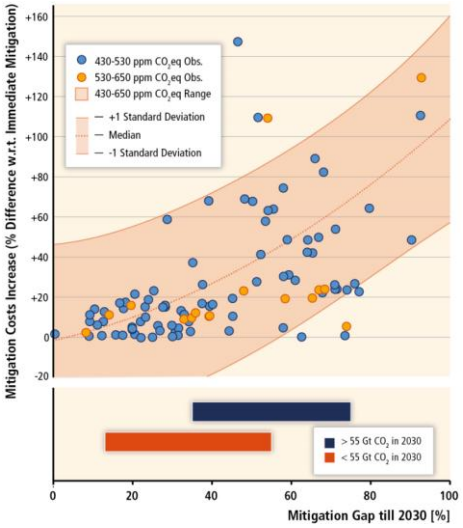
132. As regards **concentration overshoot**, Mr. Krey underlined that temporary overshooting is an integral part of all pathways that lead to a 2 °C warming (430–480 ppm category), and that this overshoot is more pronounced for the 1.5 °C limit (in fact, 1.5 °C compatible pathways typically involve temperature overshoot). He added that overshooting was explicitly considered in the 480–530 ppm and 530–580 ppm scenarios. In addition, he noted that only a few scenarios, based on two models, have examined pathways with a likelihood of staying below a 1.5 °C warming (less than 430 ppm CO_2 eq in 2100), and were not included in the quantitative analysis of the scenario literature in the report as they would have distorted the overall picture by introducing some model bias.[22] For limiting warming below 3 °C instead of 2 °C, the cumulative CO_2 budgets is two to three times higher, but emission levels in 2100 of around zero will still be required for such scenarios.

Figure 42
Possible trajectories to stay below a 2 °C limit



Source: Slide 8 of the presentation by Mr. Volker Krey (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2_krey_vuuren_sed3.pdf>. The figure illustrates that there are several emission pathways to stay under a 2 °C limit, but with varying subsequent requirements for CO_2 removal technologies (e.g. a combination of bioenergy and carbon dioxide capture and storage).

Figure 43
Increased mitigation costs resulting from delayed mitigation



Source: Slide 15 of the presentation by Mr. Volker Krey (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2_krey_vuuren_sed3.pdf>. The figure shows that late mitigation action increases the mitigation costs and deviates from an optimal, cost-effective pathway.

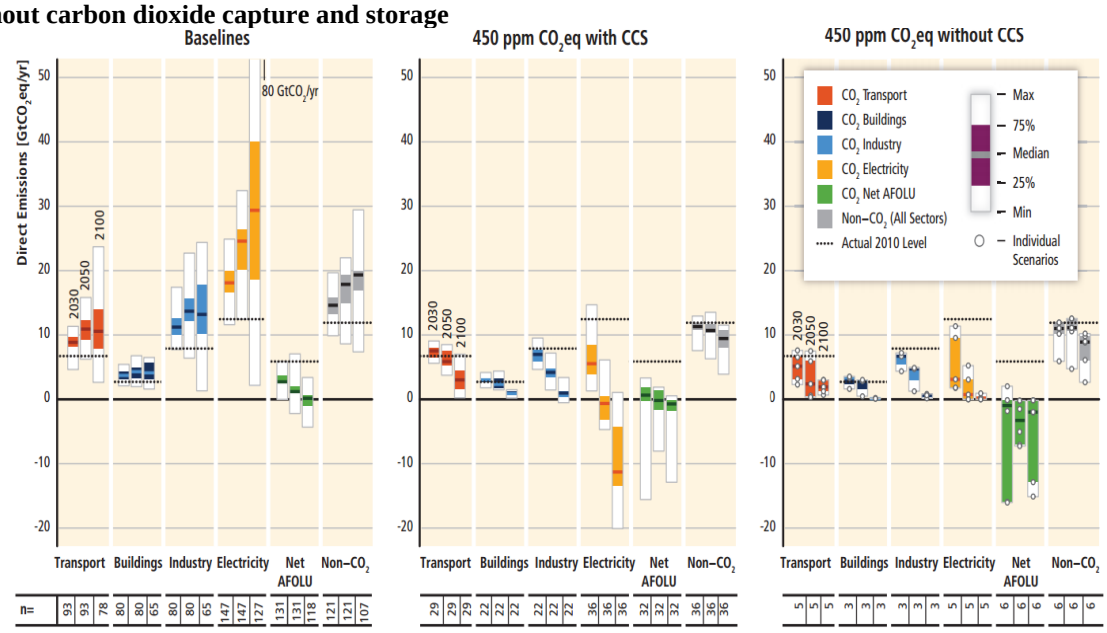
133. Regarding the **role of CO_2 removal technologies**, different trajectories are possible to reach the same target, but scenarios where early mitigation action is not taken rely heavily on negative emissions in the second half of the twenty-first century through the use of bioenergy and CCS (figure 42). The Cancun pledges are not consistent with the goal of staying under the 2 °C limit in a cost-effective manner. He stressed that mitigation costs increase if mitigation action is delayed (figure 43) or if the availability of low-carbon technologies is limited (figure 45), noting that many models were unable to produce 2 °C pathways if CCS and bioenergy technologies were not available. He added that, while mitigation costs vary widely, they are relatively modest compared to overall economic growth (see also table SPM.2). Figure 43 illustrates the increase in mitigation costs if mitigation action is delayed as a function of the mitigation gap until 2030.

[22] See the summary for policymakers in AR5 WGIII, table SPM.1, available at <http://report.mitigation2014.org/spm/ipcc_wg3_ar5_summary-for-policymakers_approved.pdf>.

134. On the issue of **sectoral emissions**, he pointed to a projected increase in emissions in all sectors according to the baseline scenarios, except for the AFOLU sector. Mitigation action in one sector depends on such action in another sector, as well as the availability of CCS and bioenergy. For example, 450 ppm CO_2 eq scenarios without CCS rely on large-scale afforestation. Some scenarios with CCS rely on negative emissions in the electricity sector that allows other sectors, such as transport, to modestly increase emissions by 2030 compared with current levels and to reduce their emissions at a slower pace thereafter (figure 44).

Figure 44

Direct sectoral CO_2 and non-CO_2 greenhouse gas emissions in baseline and mitigation scenarios with and without carbon dioxide capture and storage



Source: Summary for policymakers in the contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.7. The figure illustrates the effects of the availability of carbon dioxide capture and storage on greenhouse gas emissions in various sectors.

Abbreviation: AFOLU = agriculture forestry and other land use.

135. Ms. Joyashree Roy (IPCC) made a presentation on **sectoral and cross-sectoral mitigation**. She highlighted that **GHG emissions continue to rise in the energy supply and energy end-use sectors**, implying the need for widespread mitigation actions in order to achieve low stabilization scenarios. Almost 80 per cent of the GHG emissions growth between 2000 and 2010 comes from the energy supply and industrial sectors (figure 46). She indicated that the IPCC identified a range of low-carbon power-generating technologies that are currently commercially available or at the pre-commercial stage and estimated the specific direct and lifecycle emissions for such technologies, as well as the levelized cost of electricity, underlining that some are already cost-competitive in comparison with conventional fossil-fuel technologies.[23]

136. Regarding **energy supply mitigation options**, she noted that in the majority of low-stabilization scenarios, the share of **low-carbon electricity supply** (comprising renewable energy, nuclear energy and CCS) increases from the current level of approximately 30 per cent to over 80 per cent by 2050, and fossil-fuel power generation without CCS is almost entirely phased out by 2100. She added that in mitigation scenarios in which CO_2 eq concentration levels of 450 ppm are reached by 2100, **natural gas power generation without CCS** acts as a bridging technology, peaking before, and reaching below, current levels by 2050, and declining further in the second half of the twenty-first century. Although the energy sector was the largest GHG emitter in 2010, the importance of the industry and buildings sectors rises as indirect emissions are accounted for (figure 46).

137. With respect to the **industrial sector,** Ms. Roy emphasized that global production of minerals and manufactured products is growing steadily and driving GHG emissions. She outlined five main options for

[23] See also the technical summary in AR5 WGIII, figure TS.19, available at <http://www.ipcc.ch/report/ar5/wg3>.

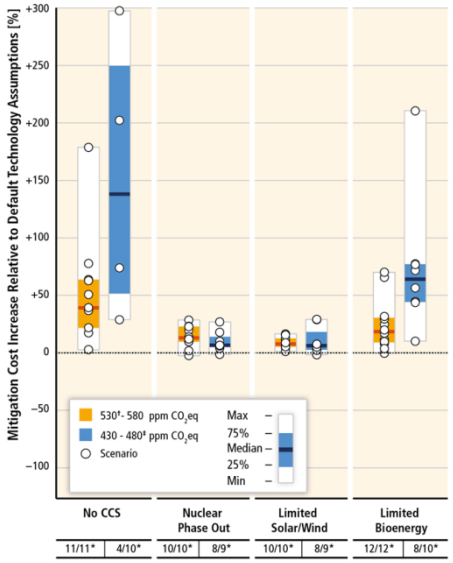
mitigating end-use sector-specific emissions: energy efficiency; emissions efficiency (e.g. switching to a non-fossil fuel electricity supply or cement production with CCS); material efficiency in manufacturing (e.g. using old steel structures without melting) or product design (e.g. lightweight car design); product-service efficiency (e.g. car-sharing or increased building occupancy); and service-demand reduction (e.g. switching from private to public transport).

138. Using the example of the steel sector, she highlighted that significant **mitigation potentials exist in various costs ranges**, including cost-effective measures. She added that attractive mitigation potentials exist in all areas and described these potentials for various sectors (figure 47).[24] In the waste sector, emissions have doubled since 1970 and mitigation measures could follow the waste hierarchy, starting with preventative measures and ending with disposal for which the cost ranges were provided.

139. In the **buildings sector**, advances in technologies and lifestyle change can significantly reduce GHG emissions by the mid twenty-first century. Efficiency improvements in the range of 25–30 per cent are available at lower costs than marginal energy supply costs. Retrofitting, with a 50–90 per cent emissions reduction potential for existing buildings, offers significant mitigation potential, and low-energy building codes could avoid lock-in. Lifestyle change and better architecture can further reduce GHG emissions in the near term to the mid twenty-first century.

Figure 45

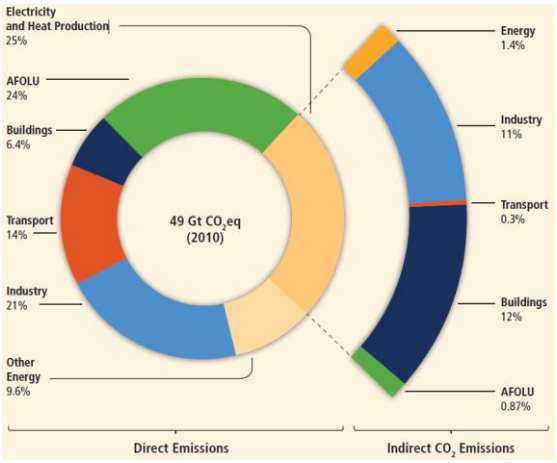
Increased mitigation costs resulting from the limited availability of technologies



Source: Slide 15 of the presentation by Mr. Volker Krey (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2_krey_vuuren_sed3.pdf>. The figure shows the increase in mitigation costs if low-carbon technologies are not freely available.

Figure 46

Total anthropogenic greenhouse gas emissions by economic sector in 2010



Source: Summary for policymakers in the contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.2. The figure shows the current contributions to emissions by sector.

Abbreviation: AFOLU = agriculture forestry and other land use.

140. In the **transport sector**, she noted that emissions will grow until 2100 according to the 'business as usual' scenario, with a faster rate for passenger transport than freight transport. She detailed the possible mitigation options with various costs for passenger and freight transport,[25] noting that some of these technologies currently have higher levelized costs than the conserved carbon, indicating that policies are needed for their deployment. Regarding **human settlements**, infrastructure and spatial planning, she stressed that urban areas account for more than half of global primary energy use and energy-related CO_2 emissions, and that the largest

[24] See also the technical summary in AR5 WGIII, figure TS.27, available at <http://www.ipcc.ch/report/ar5/wg3>.

[25] See also the technical summary in AR5 WGIII, figures TS.21 and TS.22, available at <http://www.ipcc.ch/report/ar5/wg3>.

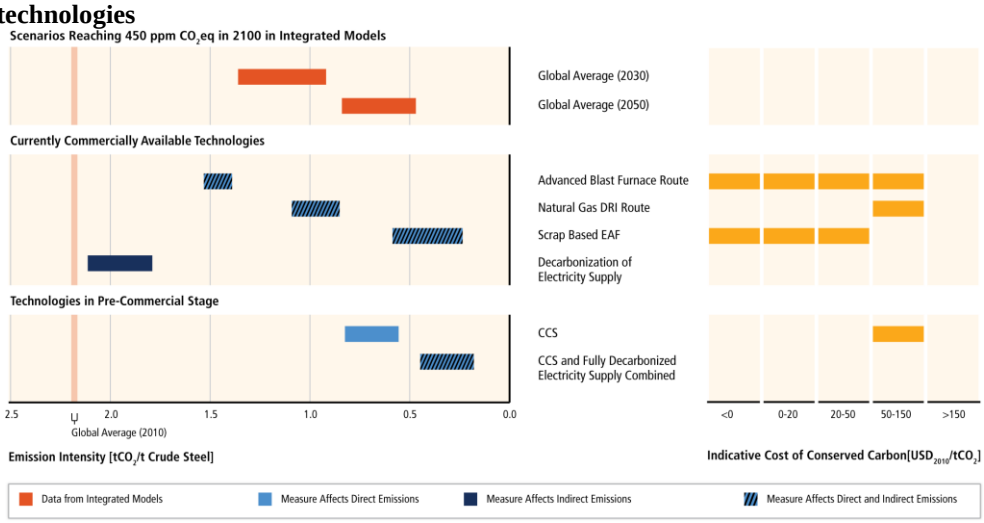
opportunities for future urban GHG emissions reduction might be found in rapidly urbanizing countries where urban form and infrastructure are not locked-in. However, she warned that governance, as well as technical, financial and institutional capacities, is often limited in such countries. In addition, significant differences exist in per capita GHG emissions between cities within a single country.

141. Regarding **AFOLU**, Ms. Roy said that this unique sector accounts for 24 per cent of total anthropogenic GHG emissions and is the only sector in which net emissions fell in the last decade. She specified that while agricultural non-CO_2 GHG emissions increased, net CO_2 emissions fell, mainly due to decreasing deforestation and increased afforestation rates (figure 48).[26] She outlined the possible economic mitigation options in the AFOLU sector, including in forestry, such as the restoration of cultivated organic soils and grazing land management, stressing the need to consider both demand- and supply-side measures.[27]

142. Ms. Roy underlined that most **systemic approaches to mitigation across the economy are expected to be environmentally and cost-effective**. Efforts in one sector determine mitigation efforts in others, thereby highlighting the importance of negative emission options in some sectors in ambitious mitigation scenarios (see para. 133 above). Reducing energy demand through efficiency enhancements and behavioural changes are key mitigation strategies.

Figure 47

Indicative CO_2 emission intensities and the levelized cost of conserved carbon for various steel production practices/technologies



Source: Slide 13 of the presentation by Mr. Joyashree Roy (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/3_roy_sed3_final.pdf>. The figure illustrates the mitigation potentials in a specific sector.

Abbreviations: CCS = carbon capture and storage; EAF = electric arc furnace.

143. In concluding, she stated that the wide application of available best-practice low-GHG technologies could lead to substantial emission reductions, and that financial and institutional barriers may be overcome by packages of complementary policies that take regional specificities into account.

144. Mr. Axel Michaelowa (IPCC) addressed the **performance of climate policies and climate finance at the international, regional and national levels**. He stressed that climate change mitigation is a global public good and thus requires international cooperation. Regarding the performance of national climate policy, he noted that from 2007 to 2012, the share of global emissions in countries with such policies rose from 45 to 67 per cent and, thus far, these policies have not significantly influenced the emissions trend. Consequently, there is a need to learn from successful examples at all policy levels to address the mitigation challenge.

[26] See also AR5 WGIII, figure 11.2(A), available at <http://www.ipcc.ch/report/ar5/wg3>.

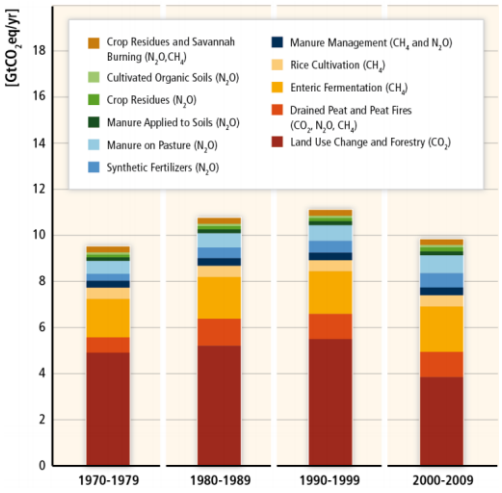
[27] See also the technical summary in AR5 WGIII, figure TS.31, available at <http://www.ipcc.ch/report/ar5/wg3/>.

145. Regarding the performance of **international climate policy**, while stressing that the UNFCCC regime is the only platform with broad legitimacy, he noted increased cooperation outside the UNFCCC, which, with the exception of the Montreal Protocol, has not led to significant emissions reductions. Although the Kyoto Protocol commitments have been reached, benefiting from changes in countries with economies in transition and the use of market-based mechanisms which mobilized low-cost mitigation, the additionality of these measures is debatable and the Kyoto Protocol has been viewed as less successful than envisaged. As regards the Cancun pledges, he stated that they are more consistent with a 3 °C temperature increase than with a 2 °C temperature increase by 2100, underlining that their impact could differ substantially depending on their interpretation (figure 49).

146. With respect to the performance of **policies at the subnational level**, Mr. Michaelowa noted the lack of evidence on the contribution to mitigation of agreements between non-State actors, highlighting the difficulties of differentiating between subnational and national efforts. With regard to the private sector, he noted that private–public partnerships work in the presence of a strong signal from government regulators; private-sector initiatives in isolation are not successful in driving down emissions; and emission reductions are driven by public policies.

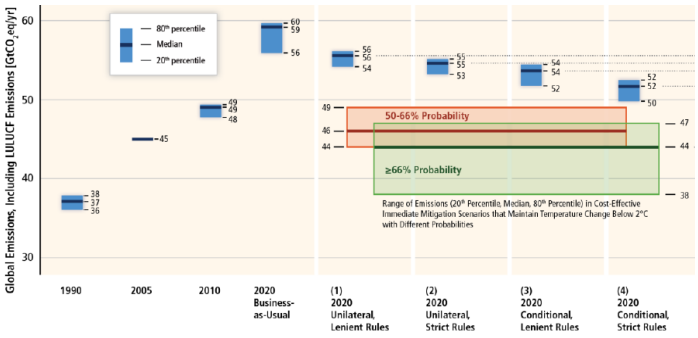
147. **Regional cooperation**, which is a new chapter in the AR5, has had only a limited positive impact on mitigation, even in areas of regional integration such as the European Union, due to unexpected economic shocks; uncertainty about the long-term emission reduction targets; and interaction with other policy instruments. Binding regulation-based approaches in areas of deep integration have had some impact on mitigation, but despite a plethora of agreements on technology, their impact on mitigation has been negligible to date.

Figure 48
Agriculture, forestry and other land use emissions over the last four decades, 1970–2010



Source: Slide 22 of the presentation by Ms. Joyashree Roy (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/3_roy_sed3_final.pdf>. The figure depicts the level of emissions over the last four decades for the agriculture, forestry and land use sector, in which emissions have decreased.

Figure 49
The Cancun pledges and the emissions pathway



Source: Slide 4 of the presentation by Mr. Axel Michaelowa (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/4_michaelowa_sed3.pdf>. The figure shows that the estimated effectiveness of Cancun pledges depends to a large extent on how they are interpreted.

148. Regarding **national policies**, he noted that the issue of co-benefits, such as energy security and local air quality, has gained increased attention, but remains to be assessed, in particular at the desegregated level. He outlined the assessment of the performance of various instruments, stressing that emission taxes are found to be more effective than voluntary mitigation. Sectoral policies are easier to implement than economy-wide policies. Some direct regulation, especially efficiency standards for buildings, cars and household appliances, is cost-

effective. Emissions trading systems introduced to date suffer from caps that are too lenient and have thus experienced price decreases. Emission taxes have been effective and can be applied in conjunction with other instruments, while the efficiency of technology policies is unclear.

149. As to the performance of **climate finance**, he indicated that total public and private **climate finance investments** are estimated at USD 343–385 billion per annum, with an almost even distribution among developed and developing countries, with 95 per cent of the investments directed at mitigation. Public climate finance is estimated at USD 35–49 billion per annum, but robust information on levels of private-sector flows from developed to developing countries is very scarce. In addition, dedicated financial instruments to decrease the risks of low-carbon technologies (e.g. credit enhancement and insurance, guarantees or finance in local currency) have rarely been applied in the context of mitigation, and performance assessment is therefore limited.

2. General discussion

150. The ensuing discussion was guided by the following questions:

(a) What will the increase in temperature be by the end of the twenty-first century without additional mitigation compared with the 'business as usual' scenario, and how do the AR5 WGIII findings on this matter compare with the findings of WGI?

(b) What mitigation pathways will limit global warming below 2 °C or 1.5 °C? What changes in emissions are required to stay below a 2 °C or 1.5 °C increase in global mean temperature relative to pre-industrial levels?

(c) What is the cost associated with the mitigation pathways for various levels of global mean warming and what will be the consequences of limited access to technologies or of delaying mitigation?

(d) What are the sector-specific emission trends, mitigation potentials, technologies and investment patterns? How do mitigation efforts in one sector influence mitigation efforts in others?

(e) Based on technology development trends, what are the low-cost abatement opportunities that can be pursued in the near term? What are the higher cost opportunities that are not yet commercially viable but could hold significant abatement potential over the longer term?

(f) What policies have attracted the greatest attention? How can we maximize climate policy co-benefits and reduce adverse side effects?

(g) What is the role of international climate change cooperation? What role can subnational actors play (e.g. the private sector, cities and sub-national authorities) in reaching the long-term global goal and creating enabling environments?

151. One Party asked whether, for the **1.5 °C limit,** the assumption was maintaining this temperature increase **for the entire twenty-first century or by the end of the century**. An expert explained that the probabilities specified in AR5 WGIII correspond to staying below a given temperature limit throughout the century. He added that there is no scenario in the data set where the global mean temperature is likely to remain below 1.5 °C throughout the century and only a few scenarios where the global mean temperature is more likely than not to remain below this limit in 2100. Another Party noted that for the 430–480 ppm category of scenarios with overshoot of less than 0.4 W/m^2 the projected temperature increase by 2100 is between 1.5 °C and 1.7 °C and, hence, the low part of these emission scenarios has a 50 per cent probability of limiting global warming below 1.5 °C.[28] The Party then asked about the required technologies and their scaling-up, the technology portfolio and the costs related to achieving these scenarios for the category with CO_2 concentration levels below 430 ppm, and how they compare with scenarios in the 430–480 ppm category that are more consistent with the 2 °C limit. The expert stated that the required technologies are the same as for the 2 °C pathway, the only difference being that they need to be deployed faster and that energy demand needs to be reduced earlier, implying a higher cost than the 2 °C scenarios. However, he added that due to the limited model studies available, the cost results lack robustness and are uncertain. Another expert added that mitigation costs for 1.5 °C scenarios increase substantially not only in the long term, but in particular also in the short term.

[28] See AR5 WGIII, table 6.3, available at <http://www.ipcc.ch/report/ar5/wg3>.

152. Another Party asked experts to **comment on how mitigation fundamentally reduces the risk of warming and climate impacts, as well as on the cost of avoided impacts**. An expert said that the mitigation costs presented in AR5 WGIII for various temperature increases are not based on a comprehensive cost–benefit analysis, which was not carried out by WGIII and would require value judgments on uncertain avoided impacts, including impacts of a "catastrophic" nature (i.e. very large impacts with a low probability). The Party further asked how to reconcile the fact that a delay in mitigation action would increase mitigation costs, and the fact that a 1.5 °C pathway would be more expensive than a 2 °C pathway. The expert drew a distinction between mitigation costs and the notion of net benefits. The 1.5 °C limit has a higher mitigation cost than a 2 °C limit, a difference which needs to be compared with avoided damages, which is the realm of WGII. He added that the costs information provided has no implications on whether or not it is worthwhile to pursue the 1.5 °C limit (see paras. 155 and 157 below).

153. In a follow-up comment on the fact that the rapid increase in mitigation costs of reaching the 1.5 °C limit may not be matched by the reduced impacts, the Party pointed out that four out of the five RFCs show that the impacts of climate change increase in a non-linear fashion between 1.5 °C and 2 °C, especially for unique and threatened systems (e.g. the massive loss of coral reefs), large-scale singular events (e.g. the disintegration of ice sheets in Greenland and Antarctica in this warming range), or impacts on local agriculture. The Party asked about the comparison between the increased costs of mitigation, the reduced costs of adaptation and the avoided non-monetary impacts between these two limits.

154. A Party commented on the usefulness of the graphic presented in figure 41 and asked if this could be generated for a 1.5 °C limit for global warming. An expert stated that a publicly available IPCC database can be used to generate such graphics for 1.5 °C, 3 °C and 4 °C limits of global warming.

155. Responding to a question regarding **the current atmospheric concentration of CO_2 eq**, an expert indicated that in 2011 the concentration was about 430 ppm CO_2 eq, noting that current concentration levels are within the lower range of the 430–480 ppm category and that it has already become evident that achieving such concentration levels in 2100 without temporary concentration overshoot will therefore be very difficult.

156. In response to a question on the **role of non-CO_2 GHGs** in achieving low-emission scenarios and possible policy implications (figure 42), an expert explained that the WGIII experts did not have the data to break down the emissions by gas at the sectoral level. He added that non-CO_2 GHGs such as methane (CH_4), nitrous oxide (N_2O) and some fluorinated gases, are dominated by agricultural sources since incentives exist in the energy sector to address CH_4 leakages. Furthermore, a switch to a less meat-rich diet and a reduction in red meat consumption would yield further CH_4 emission reductions. However, not all models are responsive to such a change in consumption patterns and many uncertainties exist in the AFOLU sector in relation to demand-side measures. Another expert added that this matter was addressed in the industrial sector. On a follow-up question related to the role of **short-lived climate pollutants** and on policies to reduce them, an expert underlined that in many cases they are co-emitted with GHGs. While recognizing that the reduction of those short-lived forcers that have warming effects is beneficial, he warned that such policies focusing on short-lived gases should not be seen as a substitute for reducing other GHGs, in particular long-lived CO_2.

157. Regarding **assumptions related to bioenergy and CCS** uptake in terms of achieving negative emissions in the second half of the twenty-first century, an expert clarified that some coordinated studies with harmonized assumptions have been carried out and are reflected in the cost estimates presented (table SPM.2). However, he emphasized that, in general, the assumptions vary greatly depending on the studies and models used to make the assessment.

158. Noting that the **costs of emissions reduction in 2050** were presented in table SPM.1 for a wide range of reductions (e.g. a 41–72 per cent emissions reduction in 2050 for scenarios likely to stay under a 2 °C limit), a Party asked if details of mitigation costs could be provided, such as costs for specific levels of emissions reduction in 2050 and marginal costs. An expert underscored that the levels of emissions reduction in 2100 are dramatically different across categories; mitigation action in 2050 is key, where emission reduction levels are different between categories; and chapter 6 of AR5 WGIII contains additional information on marginal mitigation costs. **For 1.5 °C warming scenarios, the required mitigation action in 2030 is very different from the action required for 2 °C warming scenarios**. He underlined that the cost-effectiveness of mitigation action is shown by all models and relates to the monetization of co-benefits. Another expert pointed to the difficulty of monetizing the social costs of carbon, in particular taking into account impacts, using discount rates

and considering low-probability high-impact events, which explains why WGIII confined its assessment to mitigation costs (see paras. 151 and 152 above). With regard to co-benefits, he added that it would be incorrect to directly combine the mitigation costs assessed by AR5 WGIII with the co-benefits reported in other sources of information because an evaluation of co-benefits would require an evaluation of the difference between the current level of regulation and an optimal level of regulation, for example for sulphur dioxide or black carbon. A third expert stressed the low reliability of estimated damage costs included in integrated assessment models,[29] noting that they should only be used with caution. In addition to the challenges of monetizing social costs or the choice of a discount rate, he pointed to an institutional issue, namely the gap between WGII, which studies impacts with a small number of economists, and WGIII, which has more economists but less information on impacts and on the calculation of damages.

159. A Party asked about the **differences in mitigation costs among regions and countries**. An expert said that these differences relate to burden-sharing and that in integrated systems, emission reductions to achieve a global target occur where it is cheaper to do so, without necessarily implying that the reductions are paid for by the country where they occur. Reductions could occur under an effort-sharing scheme, with carbon allowances and trade flows, as in the example presented in figure 6.30 of AR5 WGIII.

160. Regarding the **Cancun pledges**, a Party asked whether the uncertainty related to the projections beyond 2020 or to the translation of the pledges in a quantifiable emissions reduction. An expert explained that the main driver of differentials is the fact that the pledges are frequently not clearly formulated, pointing to the upper and lower values of the pledges that depend on policy decisions. Another Party asked for the experts' views on what could be done to bridge the gap between the Cancun pledges and what is required to maintain a temperature increase below 2 °C.

161. As to the **effectiveness of the Kyoto Protocol**, one Party disagreed with the expert presentation and noted that the Kyoto Protocol is the only existing rule-based instrument. He added that CDM projects have resulted in real climate change mitigation benefits, based on the robust certified emission reduction system that has mobilized over USD 215 billion of investments in developing countries as of June 2012, with USD 5–13 billion of direct benefits to developing countries, and which has resulted in over 1.5 billion tonnes of avoided CO_2.[30] Noting that it often takes time for policies to bear fruit, another Party asked about the expected results of policies in the years to come. The expert indicated that there is agreement regarding the good performance of carbon taxes over the past 20 years and the mixed experience with emissions trading over the past 10 years. Regarding market-based mechanisms, including the CDM, he recognized that a large number of projects have been generated, but clarified that what is debated by experts is whether the mechanisms always fulfil the environmental integrity target. He added that the market-based mechanisms under the Kyoto Protocol are fast in learning the experience and that the effectiveness of policies is likely to increase in the long term.

162. In response to a question on the **relationship between carbon taxes and technology policies** and on national and regional action to enhance the **effectiveness of technology policies**, an expert answered that the introduction of pricing provides incentives for technology development, pointing to some successful examples of carbon taxing and emissions trading. He added that the determination of the effectiveness of various policies aimed at the selection of a particular technology was still unclear. The Party further asked about the coverage of emissions by national climate policies. The expert said that large countries in Asia and Latin America adopted national climate polices with increased emissions coverage between 2007 and 2011, but the type and effect of these polices had not yet been assessed.

163. Regarding the **reduction of emissions in the forestry and other land use** sectors, a Party commented that although it strives to reduce its deforestation rates, these efforts "mean nothing" unless they are accompanied by emission reductions from fossil fuels and cement production, which were in the order of 10 GtC

[29] See AR5 WGIII, chapter 3, available at <http://www.ipcc.ch/report/ar5/wg3>.

[30] See *Benefits of the Clean Development Mechanism 2012*, annex B, available at <http://cdm.unfccc.int/about/dev_ben/ABC_2012.pdf>.

per year in 2010 compared with 1 GtC per year for land use,[31] as well as by the development of CCS technologies.

164. In relation to hydropower, one Party asked for clarification regarding the high emissions from electricity supply sources and the related uncertainties for hydropower emissions. Another Party asked whether the uncertainties relate to hydropower itself or to the difference between the hydropower station, such as its location, and how it is developed. An expert answered that uncertainties stem from the availability of water; competition with forest conservation; and uncertainties of policies on decentralized hydropower stations. Another expert added that location drives a range of uncertainties; for example, in tropical areas when a dam is constructed, strong CH_4 emission peaks occur in the first 10 years following the associated decomposition of biomass.

165. Several Parties asked for clarification of **public and private climate finance flows**, noting that the figures presented showed that about 10 per cent of total climate finance comes from public sources. An expert explained the debate is still continuing as to whether or not climate finance is more than just the incremental finance that drives high-carbon investments to low-carbon investments. The figure of USD 350 billion relates to the entire amount of investment, of which only a small proportion may be driven by climate change related flows, which may explain why the actual amount of public finance is much lower than the entire amount of investment. He added that the low evidence level of this finding is related to the lack of definition of what constitutes climate finance, calling for guidance at the political level on this matter. Another Party asked about the definition of public climate finance, and whether the USD 35–49 billion figure for public finance relates to total public finance or only the finance flowing to developing countries. The expert clarified that the public climate finance figures are from the fast-start period (public finance flows to developing countries).

166. One Party asked about the **timeline for achieving tariff parity in the power generation sector**, in particular among fossil fuels with CCS, renewables and nuclear energy, which would allow a seamless transition from one energy source to another. An expert pointed to the difficulties of responding to a question relating to grid parity and levelized cost of electricity, underlining that levelized cost of electricity is not a very useful indicator for identifying the optimum timing for different technologies and combining intermittent (e.g. renewables) and base-load technologies. Grid parity would require consideration of the different possible pathways to decarbonize the power sector; for example, with more renewables or with more CCS and nuclear energy. The full range of scenarios must therefore be studied, as well as the system costs of electricity, rather than the technology level.

167. Responding to a question on whether **literature published after the IPCC's cut-off date** could alter the findings of AR5 WGIII, an expert said that the additional literature would require a new assessment, noting that on the subject of bioenergy alone, roughly 5,000 peer-reviewed publications have been released over the past three years. He added that, to the best of his knowledge, there are no new findings that would fundamentally change the AR5.

F. Part 4 – theme 2: overall progress made towards achieving the long-term global goal, including a consideration of the commitments under the Convention based on the contribution of Working Group III to the Fifth Assessment Report

1. Presentations by experts

168. Mr. Gabriel Blanco (IPCC) made a presentation on trends in stocks and flows of GHGs and their drivers, explaining that the years 1970–2010 were used as a reference period, being the smallest common denominator for all gases. He added that for CO_2 emissions, some data are available until 2012, and long-term historic data are available for the period 1750–2010. Short-lived climate forcers were not included in the historic assessments due to their limited residence in the atmosphere.

169. WGIII analysed GHG stocks and flows from multiple perspectives: cumulative CO_2 emissions; GHG emissions per region, gas, sector, capita and GDP; production-based GHG emissions; and consumption-based

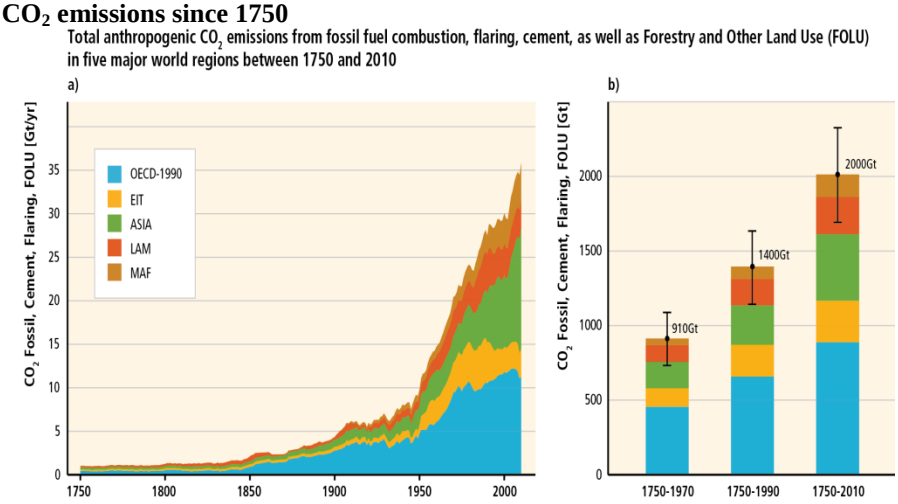
[31] See figure TS.4 in the technical summary in the contribution of WGI to the AR5, available at <http://www.ipcc.ch/report/ar5/wg1>.

GHG emissions. **Cumulative CO_2 emissions have more than doubled over the last 40 years compared to pre-industrial levels**, and annual anthropogenic GHG emissions have increased by 2.2 per cent per year over the past decade, despite reduction efforts, with CO_2 remaining the main contributing gas to these emissions (65 per cent from fossil fuels and industrial processes). Energy-related emissions increased by 36 per cent in the last decade, followed by industry (a 45 per cent increase) and transport (an 18 per cent increase). The fact that the five databases used by WGIII contain very similar data illustrates the robustness of the data sets when harmonized to cover the same sources (figure 50).

170. The comparison of **GHGs per capita and GDP per capita** shows a marked upward trend for Asia (GHG per capita grew with the increase in GDP per capita), while the trend is linear for member countries of the Organisation for Economic Co-operation and Development (OECD) (figure 51). OECD countries have larger **consumption-related emissions than production-related emissions**, while the reverse is true for the Asia region (figure 52). This is because a growing share of CO_2 emissions from fossil-fuel combustion and industrial processes in low- and middle-income countries has been released in the production of goods and services exported to high-income countries.

Figure 50

Cumulative CO_2 emissions since 1750



Source: Slide 4 of the presentation by Mr. Gabriel Blanco (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_wgiii_ar5_blanco_final.pdf>.The figure shows CO_2 emission levels for the 1750–2010 reference period.

Abbreviations: OECD-1990 = countries members of the Organisation for Economic Co-operation and Development in 1990; EIT = economies in transition; LAM = Latin America and the Caribbean; MAF = Africa and the Middle East.

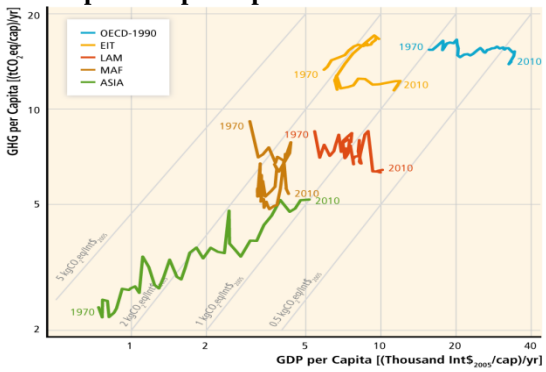
171. As regards **drivers of emissions**, Mr. Blanco drew a distinction between **immediate and underlying drivers**. The effect of **immediate drivers** of GHG emissions can be quantified, while the effects of underlying ones are more difficult to assess. Immediate drivers, or factors in the decomposition of total GHG emissions, include GDP per capita, which is the main driver of emissions, and population growth (figure 34). In the last decade, energy intensity has changed from reducing emissions to positively contributing to them, owing to a return to coal use in some countries since 2000 (figure 33). AFOLU is the only sector where the correlation between emissions and GDP growth is loose. **Underlying drivers, which are subject to policies and measures,** include fossil-fuel endowment and availability, consumption patterns, structural and technological changes, and behavioural choices.

172. Mr. Blanco underlined that both **economic and population growth have outpaced emission reductions from technological improvements in energy intensity**. Without additional efforts to reduce GHG emissions beyond those currently in place, emissions growth is expected to persist, driven by growth in global population and economic activities. Baseline scenarios result in global mean surface temperature increases in 2100 of between 3.7 °C and 4.8 °C (median values) compared to pre-industrial levels. He concluded by underscoring the need to examine the drivers of emissions when designing climate change strategies, and "looking at the past when planning for the future".

173. Mr. Sivan Kartha (IPCC) addressed the guiding question of SED 3, "How can current and future efforts to implement commitments under the Convention increase mitigation ambition and keep us on track for keeping global warming below 2° C/1.5 °C", and focused on the equity and ethical concepts relevant to international cooperation toward the long-term global goal (see para. 181(f) below). He presented three lines of argument relating to equity and equitable effort-sharing in relation to achieving the long-term global goal. The first is the **legal argument**, according to which Parties have accepted legal commitments to act against climate change in an equitable manner, with specific reference to equity in the Convention (Article 3, paragraph 1). The second is the **moral argument**, according to which it is morally proper to allocate burdens associated with the common global climate challenge according to ethical principles, which is a translation to the international level of the principles that are already generally respected at national level. The third is the **effectiveness argument**, that equitable effort-sharing will be necessary if the climate challenge is to be effectively met. This argument is based on the recognition that climate change is a global common problem. That is, effective mitigation will not be achieved if individual agents advance their own interests independently. Mr. Kartha said that this third argument is the strongest in the context of a global effort to cooperate on climate change.

Figure 51

Greenhouse gas emissions per capita versus gross domestic product per capita

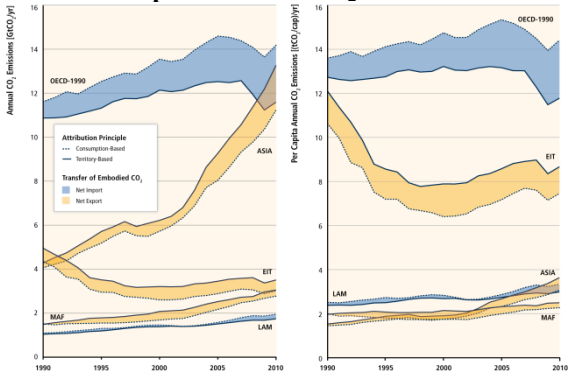


Source: Slide 9 of the presentation by Mr. Gabriel Blanco (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_wgiii_ar5_blanco_final.pdf>. The figure illustrates some of the relationships between greenhouse gas emissions per capita as a function of gross domestic product.

Abbreviations: OECD-1990 = countries members of the Organisation for Economic Co-operation and Development in 1990; EIT = economies in transition; LAM = Latin America and the Caribbean; MAF = Africa and the Middle East.

Figure 52

Production-related CO_2 emissions (territorial) versus consumption-related CO_2 emissions



Source: Slide 11 of the presentation by Mr. Gabriel Blanco (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_wgiii_ar5_blanco_final.pdf>. The figure illustrates the differences in production-related (territorial) and consumption-related CO_2 emissions.

174. Expanding on the **effectiveness argument and international cooperation**, he pointed out that no single country can protect its own climate by reducing its own emissions, and thereby no country can solve its climate change problem by itself. He underlined that countries thus undertake mitigation activities and cooperate in other ways, for example through financial and technological support, not only to directly protect their own climate, but also for the sake of inducing reciprocal effort in other countries. A country is more likely to be successful in seeking cooperation with other countries if perceived as doing its fair share of the effort. In short, a cooperative agreement based on effort-sharing that is seen to be equitable, and based on ethical principles may lead to more effective cooperation.

175. **Linking the arguments presented above with the costs of achieving the long-term global goal**, Mr. Kartha stressed that more than 100 scenarios assessed by the IPCC provide pathways for keeping global warming below the 2 °C limit (figure 35), at an estimated cost of a 1.0 to 3.7 per cent reduction in consumption relative to the baseline for 2030, or a growth reduction of 0.06 per cent per year, equivalent to around USD 1–3 trillion per year in 2030 (figure 53). He emphasized that these costs of roughly 1 to 4 per cent need to be

calibrated against a baseline growth of 300 to 900 per cent over the same period.[32] He noted that these scenarios imply stringent emission reductions starting in 2020, with global and regional emissions peaking in the next 10–15 years, which will require broad low-GHG transformation in all regions.

176. The **regional breakdown of mitigation expenditure**, based on mitigation potential (i.e. where each region undertakes mitigation up to a common equal marginal abatement cost), is as follows: the lowest expenditure is for OECD countries; it is twice that amount for Latin America; three times that amount for Asia; and four to five times that amount for Africa and the Middle East and countries with economies in transition (figure 53).[33] These figures reflect a distribution of costs that is the reverse of what might be expected if the mitigation burden was instead shared according to equity, which is at the core of the effort-sharing problem. Effort-sharing schemes have the potential to yield more equitable cost distribution across countries based on ethical principles rather than on mitigation potential. Effort-sharing approaches differentiate the mitigation costs borne in a region according to who pays for those costs, and thereby could provide a basis for compensatory payments across regions that can make climate coalitions effective and stable. There is a small set of widely invoked and rarely disputed ethical principles – founded on responsibility, capacity and equality – that forms the basis of discussions of frameworks for effort-sharing.

Figure 53

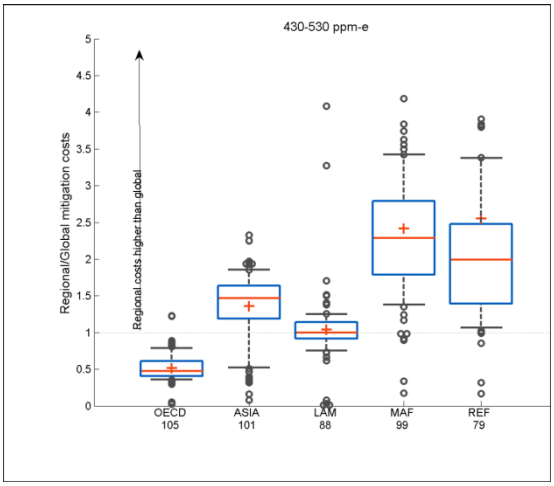
Estimated mitigation costs of a likely 2 °C limit and other emission pathways

	Consumption losses in cost-effective implementation scenarios			
	[% reduction in consumption relative to baseline]			[percentage point reduction in annualized consumption growth rate]
2100 Concentration (ppm CO_2eq)	2030	2050	2100	2010-2100
450 (430–480)	1.7 (1.0–3.7) [N: 14]	3.4 (2.1–6.2)	4.8 (2.9–11.4)	0.06 (0.04–0.14)
500 (480–530)	1.7 (0.6–2.1) [N: 32]	2.7 (1.5–4.2)	4.7 (2.4–10.6)	0.06 (0.03–0.13)
550 (530–580)	0.6 (0.2–1.3) [N: 46]	1.7 (1.2–3.3)	3.8 (1.2–7.3)	0.04 (0.01–0.09)
580–650	0.3 (0–0.9) [N: 16]	1.3 (0.5–2.0)	2.3 (1.2–4.4)	0.03 (0.01–0.05)

Source: Slide 9 of the presentation by Mr. Sivan Kartha (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2-wgiii_ar5_kartha.pdf>. The figure shows the costs of mitigation.

Figure 54

Global distribution of mitigation expenditures, as a percentage of gross domestic product



Source: Slide 13 of the presentation by Mr. Sivan Kartha (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2-wgiii_ar5_kartha.pdf>.

Abbreviations: OECD-1990 = countries members of the Organisation for Economic Co-operation and Development in 1990; LAM = Latin America and the Caribbean; MAF = Africa and the Middle East; REF = reference across scenarios.

177. As to the broader **implications of mitigation measures for sustainable development** (see para. 181(g) below), Mr. Kartha explained that for each sector, WGIII looked at the interaction of climate policies with other societal objectives, although some uncertainties remain in identifying co-benefits or adverse side effects[34] and only a partial answer can be provided to this question. He noted that there are broad interactions between mitigation and all three pillars of sustainable development (i.e. the social, environmental and economic pillars), which results from the fact that the low-carbon transition being invoked is an encompassing transition of entire

[32] This overall reduction amounts to 0.1 per cent in the most optimistic assumption to 1.2 per cent in the most pessimistic assumption combination.

[33] See AR5 WGIII, figure 6.27, available at <http://www.ipcc.ch/report/ar5/wg3>.

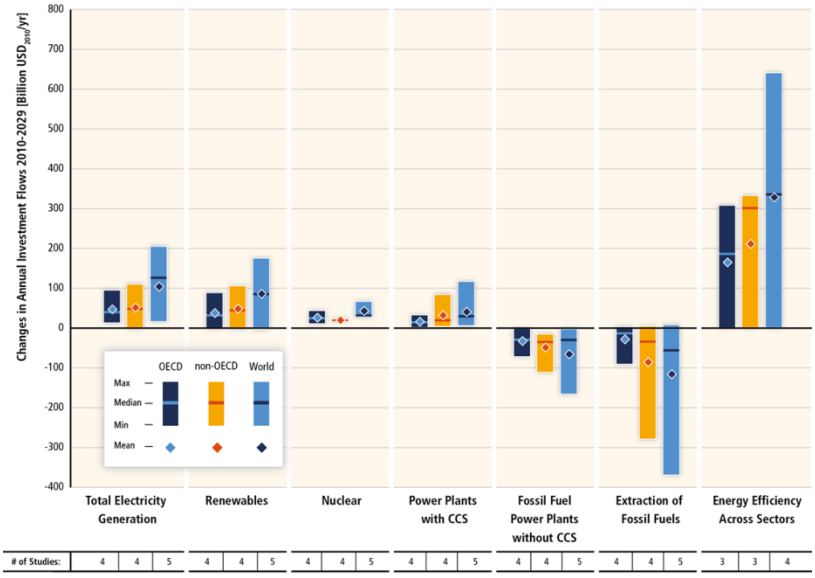
[34] See AR5 WGIII, table TS.3, available at <http://www.ipcc.ch/report/ar5/wg3>.

economic systems. Although co-benefits or adverse side effects can be substantial, they are often difficult to quantify (e.g., in monetary terms), and have not yet been thoroughly analysed. There is no "silver bullet" for enhancing co-benefits and reducing adverse side effects as they depend on local circumstances, as well as on implementation practice, pace and scale. However, practices that improve policies generally, such as good governance, transparency, stakeholder participation, cross-sectoral analysis and design, etc., are expected to help enhance co-benefits and reduce side effects. Nonetheless, these co-benefits are significant both in welfare and political terms, and managing the interactions between mitigation action and other societal goals implies mainstreaming mitigation into the broader context of sustainable development.

178. Mr. Luis Gómez-Echeverri (IPCC) made a presentation on **cross-cutting investment and finance issues** with a view to assessing the progress made towards achieving the long-term global goal. He underlined that this is the first time that an IPCC assessment report has included a chapter dedicated to climate finance and investments. He noted that there is **no** widely accepted **definition** of what constitutes **climate finance and climate investments;** scientific literature on investment and finance to address climate change is still very limited, and knowledge gaps are substantial. He presented an overview of climate finance, from possible sources of capital, managers of capital and financial instruments to adaptation and mitigation projects, and indicated that climate finance is estimated at USD 343–385 billion per year, with 95 per cent being allocated to mitigation action. Regarding the share of public versus private climate finance, flows to developing countries from public climate finance amount to USD 35–49 billion per year, and flows from private climate finance amount to USD 10–72 billion per year.

Figure 55

Limiting greenhouse gas concentrations to 430–530 ppm by 2100 requires large changes in annual investment: 2010–2029



Source: Slide 7 of the presentation by Mr. Gómez-Echeverri (Intergovernmental Panel on Climate Change), available at <https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/3_gomez_sed3.pdf>. The figure shows the required investment change by sector for a possibility of limiting global warming to 2 °C.

Abbreviations: CCS = carbon capture and storage; OECD = countries members of the Organisation for Economic Co-operation and Development.

179. Mr. Gómez-Echeverri underlined that: resources to address climate change need to be scaled up considerably over the next few decades, both in developed and developing countries; public revenues can be raised by collecting carbon taxes and auctioning carbon allowances; and emission scenarios that limit temperature increase from pre-industrial levels to below 2 °C require considerably different investment patterns during the period 2010–2029, including a fall in investments in fossil-fuel plants without CCS of USD 30 billion, an increase by USD 147 billion in investment in low-emission generation technologies, and an increase by USD 336 billion in energy-efficiency investments in the buildings, transport and industry sectors (figure 55).

180. He emphasized that **increasing access to modern energy services** to meet basic cooking and lighting needs could yield substantial improvements in human welfare at relatively low cost and with only minor effects on global GHG emission levels (USD 72–95 billion per year until 2030 to achieve nearly universal access).

181. Essential elements to scale up climate finance include: the existence of enabling environments that would allow private-sector investments to be scaled up; the de-risking of climate investment; appropriate governance and institutions at all levels; and synergies and trade-offs between mitigation and adaptation financing.

2. General discussion

182. The ensuing discussion was guided by the following questions:

(a) What are the global trends in historical, current and future GHG emissions and ambient GHG concentrations, including mitigation pathways for meeting the long-term global goal? What is the degree of probability?

(b) What are the key drivers of trends and projections of global GHG emissions and subsequent radiative forcing by sector, region and gas?

(c) Which policies and measures that appear to be reducing emissions, or that show emission reduction potential, could be strengthened, or emulated?

(d) How can long-term policy effects, such as investments in technological innovation, be evaluated? How could this possibly be factored into policymaking under the Convention?

(e) What are the assumptions for policies in the 'business as usual' scenario and what is their aggregate mitigation potential and uncertainty? Is there any gap between the actual mitigation and that needed to reach the long-term global goal and, if so, how could it be bridged? How could the implementation of these efforts be further assessed?

(f) How can current and future efforts to implement commitments under the Convention increase mitigation ambition and keep us on track to limiting global warming below 2 °C or 1.5 °C?

(g) What are the social and economic impacts of the implementation of mitigation measures on developing countries within mitigation pathways for various levels of global mean warming? What is the relationship between mitigation and impacts in terms of key risks, notably for the most vulnerable people and systems as assessed by AR5 WGII?

183. With regard to the **costs of mitigation in Africa**, the assumptions used and the question whether adaptation and disaster risk reduction were considered, an expert clarified that Africa would have the highest mitigation costs because costs have been calculated as a percentage of GDP and its GDP is low; estimates take into account not only present emission levels, but also their projected growth; and the region for which results are presented includes Africa and the Middle East. The cost figures presented are for mitigation only. In response to a follow-up question by a Party on the impacts of technological leapfrogging on the costs of mitigation in different regions, the expert stated that the acceleration of leapfrogging through, for example, a technology mechanism, would indeed reduce mitigation costs, but since historically this has only happened in few cases, there is an assumption of minimal leapfrogging built into the assessment based on models calibrated with historical data. Another expert added that middle- to high-income countries tend to replicate the historical development of high-income countries. Hence, current evidence shows that leapfrogging is limited (figure 33). Leapfrogging could be accelerated in the future, but only if there is a reliable carbon-pricing signal. In response to a question related to the identification of 'low-hanging fruits' in terms of global mitigation actions, an expert confirmed that there are indeed some indications of 'negative mitigation costs' for the building sector. He added that there are many options to decarbonize the power sector; transport will be the most challenging sector to decarbonize (few options); and carbon pricing allows finding for the detection of a way across all sectors of the economy to identify 'low-hanging fruits', taking into account the timing of mitigation action that is otherwise difficult to address. In response to a comment by a representative of civil society who pointed to some cost-effective options for the transport sector, the expert stated that achieving the low-emission scenarios in the second half of the twenty-first century requires negative emissions and therefore also depends on options to decarbonize the transport sector, irrespective of whether or not cheap electric vehicles are available.

184. Regarding **climate finance**, a Party expressed its surprise at the high **percentage of climate flows directed towards mitigation** (95 per cent) and asked if this could be related to a problem with the definition of "adaptation finance". An expert explained that the figure is in part due to the definition of adaptation finance, which is often difficult to distinguish from development or disaster risk management flows. He added that private-sector finance, which constitutes the largest part of climate finance, is definitely mostly channelled to mitigation. Responding to another question about the assumptions used in the projections of required climate finance, the expert explained that the assessment indicates that a major transformation is required to achieve the scaling-up of investment. He emphasized that elements of the enabling environment to achieve this transformation, in particular when targeted at the private sector, include greater certainty in policies, policies to lower the costs of capital, and the de-risking of investments, including a consistent carbon pricing.

185. A Party suggested **assessing progress towards the long-term global goal by breaking it down to a partial temperature limit for each decade** (e.g. 0.1 °C), based on best available science and updating it based on reduction of uncertainties and action on mitigation. An expert pointed to various difficulties of doing so, namely that: in addition to a limit in the change in global mean temperature as a long-term global goal at the end of the twenty-first century, it should be associated with a 'speed limit' at which temperature changes, which can only be assessed when the effect on impacts is also considered; the 2 °C and 1.5 °C targets can only be achieved with concentration and/or temperature overshoots; and any assessment of such an approach should therefore also be carried out in coordination with WGII. He added that the IPCC currently has no mandate to make the assessment suggested, as it would require a closer collaboration or even a merging of WGII and WGIII, but that such tasks could be part of the IPCC's future work.

186. Responding to a question on the **impact of fossil-fuel subsidy removal on emission reductions**, including on the refocusing of public expenditures, an expert explained that WGIII had not been able to carry out this quantification because of the absence of the required large-scale modelling comparison exercise. In response to a follow-up comment from a Party, he added that although no quantitative assessment has been carried out, chapter 16 of AR5 WGIII could only provide qualitative descriptions of the benefits of the removal of these subsidies. For example, reducing fossil-fuel subsidies would lower emissions and release public funds for other purposes. The expert also underlined the importance of the context in which such a removal is carried out, in particular the need for it to be accompanied by a pricing of carbon.

187. One Party noted that in the next 15 years, it will be necessary to transition from a 2.2 per cent per year increase in global emissions to an unprecedented reduction of 3 per cent per year, while the underlining drivers of emissions are increasing. The Party asked **where the focus of policymakers should lie in order to achieve the radical transformation called for in AR5 WGIII to achieve the long-term global goal**, and if such a transformation is feasible. An expert replied that all scenarios illustrate that the carbon price is a necessary condition, which should be complemented by additional policy instruments aimed, for example, at curbing carbon leakage effects and integrating all sectors, including land use. He added that significant additional research is required to design such policymaking packages. He commented that the price of carbon needs to be increased over time and that all sectors should be subject to this pricing, warning against the risk of carbon leakage if some sectors are exempt from the pricing. Responding to a follow-up question, he stressed the importance of having comprehensive carbon pricing that is not merely based on the fossil-fuel sector. To be successful, such a carbon-pricing scheme requires not only the inclusion of the land-use sector but may also call for a fundamental change in that sector. Another expert emphasized the feasibility as well as the significance of consumption patterns and behavioural changes, and underscored the importance of the Paris agreement.

188. An expert highlighted that AR5 WGIII indicates that **the required transformation is technologically feasible;** the **costs are manageable**, especially in the light of the stakes at hand; and various **policy portfolios could be deployed**. The key question is the political feasibility of the transformation, since WGIII calls for a fundamental transition that implies a "serious political challenge" with winners and losers. He added that the difficulties involved with such a near-term transition have not been assessed. Another expert pointed to the strong role of institutions in order to assess the feasibility of the required transition, calling for the capacity-building of decision makers in developing countries to enable them to make the right decisions. Responding to a follow-up question from a Party on the definition of these enabling environments, another expert noted the need to look at success stories, not least from a country-specific perspective.

189. Commenting on the **importance of pricing carbon**, a Party pointed to the uncertainties of technological developments, noting that a major technological breakthrough could generate significant mitigation benefits at

low cost and that most of the scenarios analysed do not decouple economic growth and emissions growth. An expert explained that such a technological development cannot be anticipated, but that AR5 WGIII indicates that the lowest emission scenarios can be achieved through the scaling-up of existing technologies. Any technological breakthrough would additionally improve the situation. He added that without a carbon price, technological advances will not solve the climate challenge because of the risk of a very high rebound effect. Regarding decoupling economic growth and emissions growth, an expert said both high- and low-growth pathways are possible, with the latter making it easier to achieve such decoupling. Another expert stressed that the assessment of policies shows that those that have had a consistent carbon price over a long period have been effective, whereas those that did not include such a pricing were not necessarily effective. In response to a follow-up question regarding the long-term benefits of mitigation polices, he mentioned the example of the successful use of carbon taxing in Scandinavian countries for 20 years, emphasizing that there is a sufficient body of evidence on mitigation policies that will deliver results if applied consistently. Another Party pointed to its experience with such carbon taxes and its associated quota system, underlining that to achieve a technological change, the carbon pricing should be supplemented by other policy instruments. He drew attention to chapter 6 of AR5 WGIII on transformation pathways, which can help to **determine how high the price of carbon should be set to achieve the 2 °C goal**.

190. In response to a question on the **uncertainties in the estimates of different gases**, an expert explained that uncertainties exist in all databases used in the assessment, for all gases and sectors (in the full report). However, he noted that despite the uncertainties, the upward emissions trend is clear. On a follow-up question regarding the **uncertainties related to the assumptions for 'business as usual' scenarios**, an expert explained that a large-scale modelling comparison exercise was carried out for **'business as usual'** scenarios and the uncertainties related to the assumptions were reduced. However, there are significant differences in the assumptions used for technologies, learning curves and externalities for mitigation scenarios within each model. With the establishment of the modelling community, these assumptions could be better estimated and uncertainties further reduced in the future.

191. In response to a question related to the **definition of and assumptions behind 'business as usual' scenarios**, in particular inasmuch as these relate to RCP scenarios also used by WGI, an expert explained that **WGIII 'business as usual' scenarios are typically consistent with RCP8.5, but cover a much broader range of possible future scenarios**. He added that the 'business as usual' scenarios include known polices, such as the Cancun pledges.

192. Commenting on the data on **consumption- and production-based emissions**, a Party asked for suggestions as to how to achieve substantial emission reductions in the context of globalization. Another Party noted that while the production-based emissions of OECD countries have decreased, their consumption-based emissions increased, emphasizing the need for a global perspective to effectively mitigate climate change. An expert stated that an analysis of this matter was carried out based on the available literature rather than by using data from databases. He said that there is no clear answer, underlining the need to look at all sources of emissions and their drivers, including consumption patterns and behavioural changes. Another expert added that production- and consumption-based accounting should not be used to identify responsibilities nor misused to imply particular emission reduction measures, stressing that in studies assuming an ideal world, the method used to account for emissions is irrelevant.

G. Reflections on the third meeting of the structured expert dialogue

193. SED 3 was well attended, bringing together many government delegates and experts from all regions, as well as civil society representatives. During each of the four parts of the meeting, the time dedicated to discussions was substantial and balanced between the two themes of the 2013–2015 review. Parties actively engaged in a rich exchange of views with experts that enabled an in-depth discussion of the findings of AR5 WGII and AR5 WGIII as they pertain to the 2013–2015 review. SED 3 saw Parties and IPCC experts engage in a remarkably constructive, productive and rich manner in all discussions. Consequently, the dialogue was deepened, with many follow-up questions and comments. We believe the productive and informative discussions at SED 3 supported Parties in internalizing the key findings contained in AR5 WGII and AR5 WGIII, which are relevant to both themes of the 2013–2015 review, thus completing the consideration of the contributions of all three working groups to the AR5.

194. At SED 2, a number of issues were identified as requiring further consideration at SED 3, namely: risk management, including the relationship between risk and overshooting of the long-term global goal, the geographical distribution of risks given regional differences in impacts and in economic or other costs of adaptation for various levels of warming; and the underlying assumptions, feasibility and cost of impacts, mitigation and adaptation in terms of RCPs and other scenarios considered by the IPCC, as well as the temporal aspects of emission pathways while considering aspects such as short-lived GHGs and commitments in carbon infrastructure. At SED 3, these issues were fully addressed by the IPCC experts in their presentations and during the discussions with Parties.

195. Nonetheless, the discussions at SED 3 underlined a number of issues where additional information and discussions would be required at future meetings of the SED, including: the evaluation of the costs of adaptation; the assessment of the value of the co-benefits of climate change mitigation; and the assessment of the 1.5 °C temperature limit. However, the IPCC repeatedly emphasized that their hands are tied, pointing out that scientific insights on the 1.5 °C limit are limited since results of the needed research are not yet available or not of the same robust nature as those on the 2 °C long-term global goal.

196. At SED 3, IPCC experts stated repeatedly that assessing the adequacy of the upper limit for global warming in the light of Article 2 of the Convention involves both risk assessments and value judgments. In the AR5 the IPCC assessed risks across contexts and through time, providing an analytical framework that can be a foundation for a collective agreement on how much global warming is acceptable. While recognizing that the work of the SED is still ongoing, it is already a successful vehicle for informing and supporting policy formulation, taking into account the various values and recognizing that what constitutes an intolerable risk may differ across sectors, regions and countries.

197. One of the clear messages that emerged from SED 2 and SED 3 is that limiting global warming to below 2 °C calls for adopting a long-term approach to climate change, which in turn calls for science-based management of the global pathway towards a low-carbon and climate-resilient future. To that end, the SED has been able to contribute considerably to an increased understanding of the relationship between near- and long-term actions on mitigation and adaptation. Furthermore, the periodic review of the long-term global goal can play a positive and essential role in any process established for assessing the progress made towards achieving the long-term global goal, thereby strengthening the science–policy interface.

198. We, the co-facilitators, believe that the approach taken at SED 3 worked well and we congratulate Parties and experts for a successful meeting, while encouraging all stakeholders to maintain this positive and collaborative spirit at future meetings of the SED.

Annex IV

Summary report on the fourth session of the structured expert dialogue

I. Introduction

A. Mandate

1. At their thirty-ninth sessions, the Subsidiary Body for Scientific and Technological Advice (SBSTA) and the Subsidiary Body for Implementation (SBI) requested us, the co-facilitators of the structured expert dialogue (SED), to organize SED meetings in 2014 in conjunction with the fortieth and forty-first sessions of the subsidiary bodies.[1]

2. In response to the above-mentioned mandate, we convened the 1st meeting of the fourth session of the SED (SED 4-1), on 2 and 3 December 2014, in Lima, Peru, during SBSTA 41 and SBI 41 to consider the Synthesis Report (SYR) of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5),[2] as well as other information from the sources referred to in decision 2/CP.17, paragraph 161 (b–d).[3] Prior to SED 4-1, we provided Parties with an information note outlining our approach to the organization of the meeting.[4]

3. SBSTA 40 and SBI 40 requested the co-facilitators of the SED to convene an additional meeting of the SED after SBSTA 41 and SBI 41, in conjunction with a meeting of the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP) and prior to SBSTA 42 and SBI 42, to consider further inputs referred to in decision 2/CP.17, paragraph 161, in particular its subparagraphs (b–d), with a view to closing the SED prior to SBSTA 42 and SBI 42 in accordance with decision 1/CP.18, paragraph 91.[5] As indicated at SBSTA 41 and SBI 41,[6] the 2nd meeting of the fourth session of the SED (SED 4-2) was held on 8 and 9 February 2015 in Geneva, Switzerland, in conjunction with the eighth part of the second session of the ADP. Prior to SED 4-2, we provided Parties with an information note outlining our approach to the organization of the meeting.[7]

B. General objective and approach of the meeting

4. SED 4-1 focused on the AR5 SYR, which distilled and integrated the key elements of the contributions of the three IPCC Working Groups to the AR5, as well as the two IPCC special reports produced during the fifth assessment cycle, which are relevant to both themes of the 2013–2015 review, and information sources other than those of the IPCC identified in decision 2/CP.17, paragraph 161(b–d), with a view to complementing, summarizing and conceptualizing the information already discussed at previous SED meetings. At its final meeting, the SED aimed to complete its work by addressing, in a balanced manner, all remaining inputs to the 2013–2015 review and information that has been published after the cut-off dates of the IPCC AR5, and by identifying information gaps.

5. Accordingly, we organized SED similarly to previous SED meetings as a fact-finding exchange of views between experts and Parties. Experts from the IPCC, processes under the Convention, United Nations agencies and other organizations presented findings from their reports, and highlighted their relevance to both themes of

[1] FCCC/SBSTA/2013/5, paragraph 133, and FCCC/SBI/2013/20, paragraph 167.
[2] Available at <http://unfccc.int/7521.php>.
[3] FCCC/SBSTA/2014/2, paragraph 74, and FCCC/SBI/2014/8, paragraph 193.
[4] Available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/sed4_informal_note_14_nov.pdf>.
[5] FCCC/SBSTA/2014/2, paragraph 75, and FCCC/SBI/2014/8, paragraph 194.
[6] FCCC/SBSTA/2014/5, paragraph 46, and FCCC/SBI/2014, paragraph 109.
[7] Available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/information_note_sed_4-2_final.pdf>.

the 2013–2015 review. In addition, regional research centres presented on observed impacts of climate change. These presentations were followed by a moderated discussion guided by questions prepared by the co-facilitators[8] based on questions provided by Parties through their submissions,[9] questions from participants and additional questions provided by some Parties before each part of the meetings.

II. Summary of the proceedings

6. SED 4 consisted of two meetings,[10] while the deliberations were organized in four parts and were open to all Parties and observers. Part 1 was held on 2 December 2014 (3–6 p.m.), part 2 was held on 3 December 2014 (3–6 p.m.), part 3 on 8 February 2015 (3–6 p.m.) and part 4 on 9 February 2015 (10 a.m.–1 p.m. and 3–4.30 p.m.). SED 4-1 comprised parts 1 and 2, and SED 4-2 comprised parts 3 and 4. The meetings were chaired and moderated by us, the co-facilitators.

7. **SED 4** was opened by Mr. Manuel Pulgar-Vidal, President of the Conference of the Parties (COP) at its twentieth session and the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (CMP) at its tenth session. Noting that the United Nations Climate Change Conference held in Lima is a **key time and place to reconcile science and policy**, he said the AR5 SYR has already highlighted some topics and outlined options that we should take into account in order to "move the decision making process towards success". While recognizing that the SED is still ongoing, he stated that it has already been effective in enabling a science-based management of the global pathway towards a climate-resilient future. Noting that this is the first time such a review has been carried out, he said that COP 21 is expected to take appropriate action on the basis of the outcomes of the 2013–2015 review and underlined that the meeting of the SED will be an essential part of this outcome as it aims to distill and conceptualize the available relevant information with a view to conclude the review. Mr. Pulgar-Vidal added that by the end of 2015 "we aim to have a solid and strong agreement". Noting that citizens are aware of the science that has been delivered to policy makers, he said it is now up to them to show they are acting on that basis.

8. Mr. Andreas Fischlin, a co-facilitator of the SED, outlined the structure of the meeting, noting that the discussion would focus on the two themes of the review: the adequacy of the long-term global goal in the light of the ultimate objective of the Convention (theme 1), and overall progress made towards achieving the long-term global goal, including a consideration of the commitments under the Convention (theme 2), which will be addressed in a balanced manner. He explained that part 1 will focus on the AR5 SYR while part 2 will consider non-IPCC information sources. Although experts will make presentations on both themes, separate discussions will be held on each. Mr. Fischlin stressed the need to finish complementing and start conceptualizing the information considered by the SED in order to finish the dialogue soon. He encouraged IPCC experts to focus on information coming from the distillation of the contributions of the three Working Groups to the AR5 and the SYR, and invited Parties to make succinct interventions to allow for a fruitful dialogue.

9. **Part 1** of the meeting opened with an introductory presentation made by an IPCC expert on the overarching findings of the AR5 SYR that are relevant to both themes of the 2013–2015 review. Subsequently, two presentations focused on: the adequacy of the long-term global goal in terms of preventing unacceptable consequences for ecosystems and food production, and for sustainable economic development; and on the adequacy of the 2 °C upper limit of temperature rise in terms of risk management within planetary boundaries and progress towards the long-term global goal. The presentations were followed by a substantive discussion guided by questions.

10. **Part 2** of SED 4-1 focused on information from United Nations agencies and intergovernmental organizations relevant to the 2013–2015 review. A SED co-facilitator, Mr. Zou Ji, opened the meeting by explaining that presenters from United Nations organizations and intergovernmental organizations would address: the mitigation and adaptation gaps; food production and security; the health impacts of climate change and mitigation co-benefits; how to set the price of carbon; and the decarbonization of the energy system as well

[8] For the list of questions, please see the SED 3 agenda, available at <http://unfccc.int/7521.php>.

[9] The submissions from Parties are available at <http://unfccc.int/science/workstreams/the_2013-2015_review/items/7590.php>.

[10] See paragraphs 2 and 3 above.

as related technology perspectives. He added that presenters would also describe relevant activities by their organizations to support progress towards achieving the long-term global goal, as well as best practices and lessons learned in streamlining support that can lead to effective mitigation of, and adaptation to climate change. Mr. Zou Ji stressed that although presenters would address both of the two themes of the review, their presentations would be followed by separate discussions on themes 1 and 2.

11. Part 2 started with presentations on key findings of the United Nations Environment Programme (UNEP) *The Adaptation Gap Report 2014*[11] and *The Emissions Gap Report 2014*,[12] followed by a presentation by the Wold Bank, which focused on the need to reduce **net carbon dioxide (CO_2) emissions to zero,** elements common to all models that provide the emission reductions required to bring emissions to zero at the end of the century, the role of carbon pricing and climate change impacts in a world 4 °C warmer. The International Energy Agency (IEA) presentation focused on the challenges and opportunities related to energy and climate change, describing: the current state of the energy sector, modelling results and five key actions to achieve a low-carbon energy sector, and issues related to technology risk and risk management. The World Health Organization (WHO) presentation focused on the health impacts of climate change and the Food and Agriculture Organization of the United Nations (FAO) presentation focused on agriculture, food security and climate change. The presentations were followed by a substantive discussion guided by questions.

12. **SED 4-2** took place on 8–9 February 2015 in Geneva, Switzerland. The meeting consisted of two parts. On 8 February, part 3 of SED 4 focused on information from United Nations agencies, international organizations and processes under the Convention. On 9 February, part 4 considered regional and emerging information. Mr. Zou Ji welcomed delegates and opened the meeting.

13. In his opening remarks, Mr. Tomasz Chruszczow, the Chair of the SBSTA, addressed the relationship between the SED and the joint contact group on the 2013–2015 review, which was established by the SBSTA and SBI. He said that the report on SED 4 and the final factual report on the SED (to be prepared by the co-facilitators) will constitute key inputs to the work of the joint contact group when it meets during the forty-second sessions of the subsidiary bodies in June 2015 to formulate recommendations to the COP on the 2013–2015 review, including on a possible decision and appropriate action for consideration by the COP.

14. Mr. Chruszczow then outlined some key messages emerging from the meetings of the SED so far, focusing on theme 1 of the 2013-2015 review, the adequacy of the long-term global goal:

(a) The first message was on the nature of the 2 °C and 1.5 °C limits to global warming. He emphasized that at SED 2, SED 3 and SED 4-1, many experts, notably from the IPCC, had explained that climate-related impacts are prevalent at the current degree of warming of 0.85 °C above the pre-industrial level and have increasingly significant adverse effects, and that additional magnitudes of warming will only increase the risks of severe, pervasive and irreversible impacts. He stressed that this is an indication that any upper limit for global warming can no longer be seen as a guardrail providing protection from dangerous anthropogenic interference, and called for a consideration of societally, or otherwise, acceptable risks of climate impacts;

(b) The second message was related to the adequacy of the upper limit for global warming. Mr. Chruszczow noted that at SED 3, IPCC experts stated repeatedly that assessing this adequacy in the light of Article 2 of the Convention involves both risk assessments and value judgments, and indicated that climate change related risks from extreme events and risks to unique and threatened systems are high with additional warming of around 1 °C. He stated that this provides a solid analytical framework that can provide a foundation for a collective agreement on how much global warming is acceptable;

(c) The third message focused on the limitations related to working with a temperature limit only. He emphasized that at SED 2 and SED 3, experts had pointed to some of these limitations, in particular in relation to the global mean sea level rise or ocean acidification, but underscored that such limitations do not change the basic finding emerging from an assessment of the temperature limit, namely that we need to take urgent and strong action, on the contrary as experts had pointed out. He suggested that in the long term, the scientific community should think about ways to integrate the climate (and climate modelling) component into a larger framework related to the climate, society and the economy, where the climate is not just the outcome of

[11] Available at <http://www.unep.org/climatechange/adaptation/gapreport2014/>.
[12] Available at <http://www.unep.org/publications/ebooks/emissionsgapreport2014/>.

prescribed emissions, but where levels of impacts to be avoided can be translated into emissions and policies, and where climate change influences technology and societal choices on mitigation and adaptation;

(d) The fourth message has to do with the need to translate the AR5 findings to regional and national levels. He added that understanding the implications of the 2 °C goal at the national level calls for, inter alia, a systematic observation system that has high spatial and temporal resolution to better support adaptation, a better understanding of how much climate change is taking place at the regional level and a focus on regions with the highest vulnerability.

15. After providing an overview of SED 4-2, he indicated he believes that the review process has already shown to be a successful and promising vehicle to inform and support policy formulation, taking into account various values, while recognizing that what constitutes an intolerable risk may differ across sectors, regions and countries. He also stressed that the review of the adequacy of the long-term global goal calls for science-based management of the emission pathway, including all the relevant dimensions of science. The collaboration between the SBSTA and the IPCC to ensure that such a science-based management of the pathway is carried out will be essential for this review and beyond. In this context, he remarked that the IPCC is currently discussing and agreeing on its future work, including on the terms of its next assessment cycle. He also mentioned decision 12/CP.20, in which the COP invited the IPCC to take into account the work of the UNFCCC in determining its future products and assessment cycles. He emphasized that this "may well bring about a further strengthening of the science–policy interface" enabling the science-based management of the pathway to a low-carbon, climate-resilient future.

16. In closing, Mr. Chruszczow emphasized that the SED represents a significant and promising step forward in terms of bringing together the science and policy worlds.

17. Mr. Amena Yauvoli, SBI Chair, also delivered some opening remarks, focusing on theme 2 of the 2013–2015 review, the overall progress made towards achieving the long-term global goal. He stressed the timeliness of the review of the long-term global goal within the UNFCCC process and global climate policy in general, noting that 2015 will be a key year for global action on climate change. He underlined that the accelerating growth in CO_2 emissions that has occurred since 2000 has implications for the probability of limiting warming to 2 °C above pre-industrial levels, based on the cumulative emissions since 1750. He cited findings of the IPCC AR5 indicating that total anthropogenic emissions of greenhouse gases (GHGs) have continued to increase from 1970 to 2010, with larger absolute decadal increases towards the end of this period, despite a growing number of climate change mitigation policies, and that 40 per cent of the cumulative emissions were emitted since 1970.

18. Mr. Yauvoli stated that a message emerging from the review relates to the feasibility of the 2 °C limit in the context of a risk management approach to decision-making on climate change. He said that, as presented by the IPCC at SED 3, limiting warming below 2 °C is still both technically and economically feasible, but requires fundamental changes and entails risks associated not only with climate impacts but also, for example, with technology development and diffusion, since they are needed at an unprecedented scale. He underlined that the urgency of these changes is exacerbated in order to achieve a 1.5 °C limit and stressed costs, technology lock-in, and loss and damage among the consequences of delayed action.

19. He then focused on the imperative to track the development, adoption, implementation and effects of policies and measures undertaken by countries to advance their transition to a low-carbon economy, and the shift to a science-based management of the pathway to a low-carbon future. He underlined the importance of achieving a more seamless process in the scientific assessment of progress made towards limiting temperature increase below 2 °C, pointing to the need for countries to translate global numbers to the national level, as well as to aggregate national contributions and assess their impact on the global pathway. In this context, he emphasized the relevance of the multilateral assessment process conducted under SBI.

20. Mr. Yauvoli provided an update on the international assessment and review process for developed country Parties, noting that the first round of the multilateral assessment process was held in Lima, in December 2014, with the multilateral assessment of the progress of 17 Parties included in Annex I to the convention (Annex I Parties) towards their emission reduction targets. He explained that the Party records for these 17 Parties would be published at the end of February 2015, and that the remaining Annex I Parties would be assessed at SBI 42 and 43. On the multilateral assessment of developing countries, he explained that 10 Biennial Update Reports (BURs) by developing countries had been received and posted on the UNFCCC website, and

that the process of international consultation and analysis (ICA) of BURs had been initiated, with the first round of the workshops under the SBI for the facilitative sharing of views expected in 2016–2017.

21. Among the objectives of the multilateral assessment, he cited: enhancing trust among countries regarding the extent of national action; determining the extent to which needed reductions are likely to occur as a result of existing approaches; improving targeting of international assistance and climate finance to address key barriers; and helping countries learn from one another's experience.

22. Mr. Yauvoli also pointed to remaining challenges in bringing together under the 2013–2015 review the best available information from science and national information available in reports from Parties and other processes under the Convention, noting that a number of reports from the multilateral assessment will not be available on time for them to be considered by the 2013–2015 review. He therefore called for carrying forward beyond the 2013–2015 review the link between national information and that from science, while expressing the hope that progress achieved under the 2013–2015 review could benefit future work relating to a science-based management of the global pathway towards a low-carbon and climate-resilient future, thereby strengthening the science–policy interface. Nonetheless, he said that the 2 °C goal has been catalysing many actions since Cancun, and that through the preparation by Parties of their intended nationally determined contributions (INDCs), action is expected to be further catalysed. Emphasizing the importance of transparency of national contributions for the robustness of the 2015 agreement, he said that the multilateral assessment process captures progress on emission reductions and that such a tracking system is needed. However the current tracking system for adaptation and means of implementation (MOI) is less mature than for mitigation, in part due to the scarcity of the needed information.

23. While noting that significant efforts have been made on adaptation, finance, capacity-building and technology transfer, he said they need to be strengthened. Mr. Yauvoli then reported on ongoing work on national adaptation plans (NAPs), which is carried out under the SBI. He explained that under the NAP process, each country determines the level of risk to which it seeks to adapt and coordinates the support required. NAPs will therefore be a key document on national adaptation needs and priorities, which may also include information on costs. He explained that the initial guidelines for the NAP process include a reporting, monitoring and evaluation element. It is therefore an ongoing process that will enable countries to formulate and update their adaptation plans and objectives regularly, in light of the emerging science. As such, he said, the NAP process will be part of the tracking of progress towards the long-term global goal as it relates to adaptation.

24. In closing, he stated that 2 °C is the internationally agreed upper limit for global warming that will guide and catalyse our future actions and raise ambitions, and that the review is a comprehensive process that looks at the climate 'problem' and 'solutions' in an integrated manner.

25. **Part 3** focused on information from United Nations agencies and international organizations, and from processes under the Convention. It started with a presentation by the Adaptation Committee (AC), which was followed by two presentations by: the Convention on Biological Diversity (CBD), addressing matters relating to the linkages between biodiversity and climate change mitigation and adaptation; and the United Nations Convention to Combat Desertification (UNCCD), focusing on desertification and land degradation and their impacts on natural ecosystems and food security. A final presentation illustrated the work of the SBI supporting adaptation and mitigation action through capacity-building including the role of education for mitigation and notably adaptation. The presentations were followed by a substantive discussion guided by questions.

26. SED co-facilitator, Mr. Fischlin, welcomed delegates to part 4 of SED 4 and explained that pursuant to a request by a group of Parties and Article 4, paragraph 8, of the Convention, this part would hear regional perspectives on the observed impacts of climate change. He emphasized that other organizations cannot compete with the IPCC in terms of the rigor of its review process, which is why the COP agreed to the AR5 being a key input into the 2013–2015 review.

27. **Part 4** focused on regional and emerging information. It started with presentations by regional centres in the Caribbean, Pacific and the Arctic, illustrating observed impacts of climate change in these regions, followed by a presentation on agriculture and food security in a changing climate with a focus on tropical regions. A final presentation by the World Meteorological Organization (WMO) illustrated emerging information on the state of the climate published after the AR5 cut-off dates. As in the previous three parts, the presentations were followed by a substantive discussion among experts and Parties guided by questions.

III. Summary of the discussion

A. Part 1: Introductory presentation on the Synthesis Report of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

1. Presentations by experts

28. Ms. Renate Christ, Secretary of the IPCC, delivered a presentation on behalf of the Chair of the IPCC, which emphasized the added value of the integration and synthesis of the work of the three Working Groups of the IPCC. She outlined the key findings emerging from the AR5, including that: **human interference in the climate system is clear**; **the more we disrupt our climate, the more we risk severe, pervasive and irreversible impacts**; and **we have the means to limit climate change and build a more prosperous, sustainable future**.

29. Ms. Christ noted that **anthropogenic GHG emissions have increased** since the pre-industrial era, owing largely to economic and population growth.[13] These emissions are now higher than ever, with atmospheric concentrations of CO_2, methane (CH_4) and nitrous oxide (N_2O) at levels unprecedented in at least 800,000 years. **Climate impacts are already occurring** and the changes in extreme weather and climate events observed since about 1950 have been linked to human influence and include a decrease in cold temperature extremes and an increase in warm temperature extremes, extremely high sea levels, and an increase in the number of heavy precipitation events.

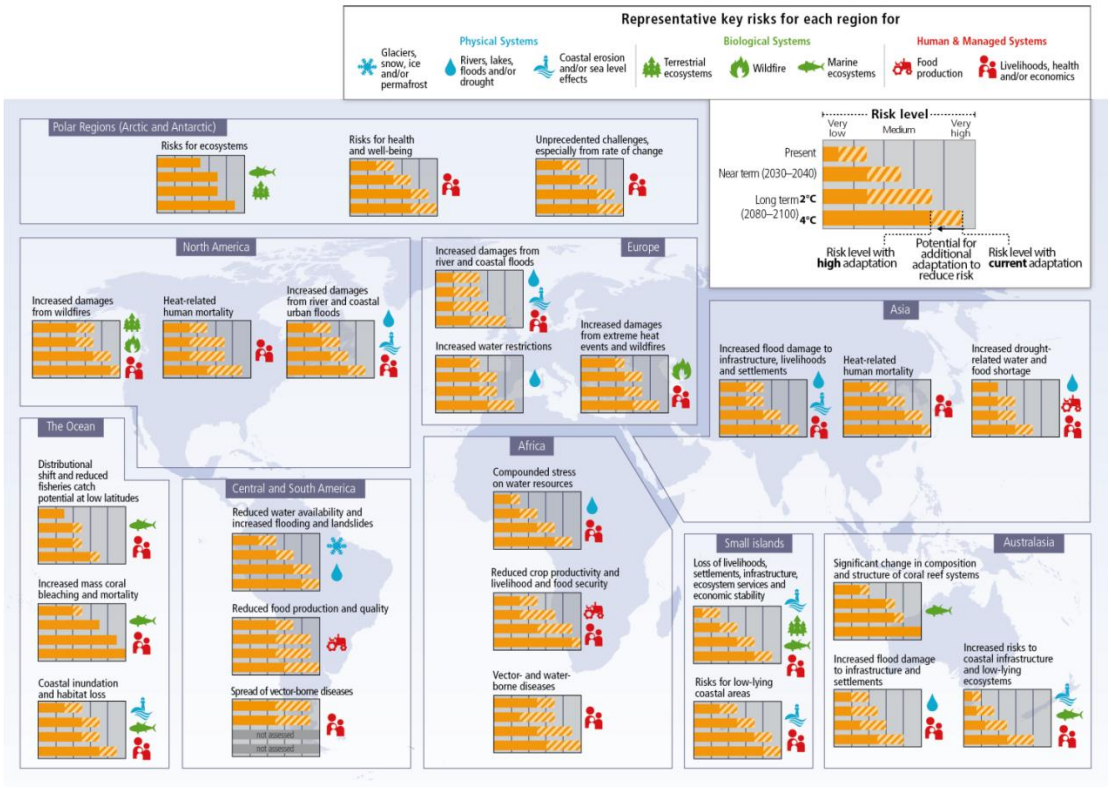
30. She stressed that continued emissions of GHGs will cause further warming and changes in the climate system, and that continued warming increases the risks of severe, pervasive and irreversible impacts. She added that some risks are already considerable, even at a 1 °C global temperature increase above pre-industrial levels, and are high to very high for increases of 4 °C or more. People who are socially, economically, culturally, politically, institutionally or otherwise marginalized are the most at risk.

31. She explained that the **AR5 has assessed the risks at present, for the near term and for the long term**, considering, for the latter, warming of 2–4 °C above pre-industrial levels. This assessment of risks is presented by regions and by sectors, as well as for physical, biological, and human and managed systems. The IPCC has also assessed the potential for adaptation in terms of limiting the risks of climate change and the limits to adaptation (figure 56).

[13] See figure 12 and paragraph 110 of the summary report of SED 3, available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/sed3_summary_report.pdf>.

Figure 56

Representative key risks for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation



Source: Summary for policymakers in the Synthesis Report of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.8. The figure shows representative key regional risks, assessed as very low, low, medium, high, or very high. Risk levels are presented for three time frames: present, near term (2030–2040), and long term (2080–2100). The long term is shown twice for a mean warming of 2 °C and 4 °C above pre-industrial levels.

32. Ms. Christ indicated that in the context of limiting temperature increase to 2 °C above pre-industrial levels, the AR5 has assessed that: a **combination of adaptation and substantial, sustained reductions in GHG emissions can limit climate change risks**; measures exist to achieve the substantial emission reductions required to limit likely warming to 2 °C above pre-industrial levels (**40–70 per cent reduction in GHGs globally by 2050, and near-zero or below-zero emissions levels in 2100**); implementing these GHG reductions implies various substantial technological, economic, social and institutional challenges; ambitious mitigation does not come without costs, but is affordable, and estimated costs do not account for the benefits of reduced climate change, and delaying mitigation will substantially increase the challenges associated with limiting warming to 2 °C above pre-industrial levels.

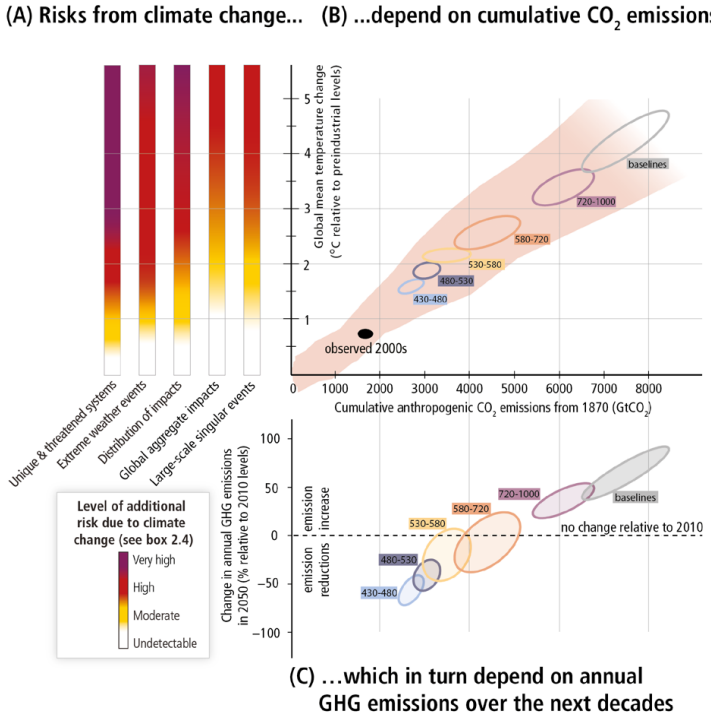
33. She outlined common **mitigation measures available**, such as: increasing: the efficiency of energy use; the use of low-carbon and no-carbon energy technologies, many of which already exist; improved carbon sinks such as bioenergy combined with carbon capture and storage (BECCS); and lifestyle and behavioural changes. She also mentioned the need to: **nearly quadruple zero- and low-carbon energy supply from renewable energy by 2050**, and to **reduce deforestation, improve forest management and plant new forests**.

34. Ms. Christ emphasized that the link between **climate change and equity** has received a lot of attention and stressed the importance of assessing the issues of equity, justice and fairness raised by mitigation and adaptation action. In this respect, she highlighted different past and future contributions to the accumulation of GHGs in the atmosphere, different capacities to address mitigation and adaptation and varying challenges and circumstances. Capacities to address mitigation and adaptation vary, and insufficient adaptation would have a present impact on the potential for sustainable development. She added that options for equitable burden-sharing can reduce the potential for the costs of climate action to constrain development.

35. She introduced a graph illustrating the level of risks assessed by Working Group II (WGII) of the IPCC in its contribution to the AR5, including in regard to the five reasons for concern (RFC), for various levels of temperature increase (figure 57). *Mr. Stéphane Hallegatte, IPCC,* described how this figure connects actions with consequences for climate change by bringing together knowledge from the three IPCC Working Groups to illustrate that the risks from climate change depend on cumulative CO_2 emissions.

Figure 57

The relationship between risks from climate change, temperature change, cumulative carbon dioxide emissions and changes in annual greenhouse gas emissions by 2050



Source: Summary for policymakers in the Synthesis Report the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.10. The figure shows the relationship among risks from climate change (panel A), temperature change and cumulative CO_2 emissions (panel B), and changes in annual GHG emissions by 2050 (panel C). See also figures 58, 59, 63, 64, 68 and 69 for additional explanations and considerations.

Abbreviations: GHG = greenhouse gas; 430–480 = scenarios leading to a concentration of 430–480 ppm CO_2 equivalent in 2100

36. He explained that limiting risks across the five RFC for a given increase in global mean temperature change (panel A) would imply:

(a) In the **long term, a limit for cumulative CO_2 emissions** (panel B). This panel brings together information from: Working Group I (WGI) models (pink plume), which include the uncertainty from non-CO_2 gases and climate and carbon uncertainty, using likely ranges; and Working Group III (WGIII) models for different categories of scenarios (ellipses), which do not include climate and carbon cycle uncertainty but explore more comprehensively the scenario's uncertainty for a range of CO_2 and non-CO_2 pathways, while considering cost effectiveness. While the carbon budget for a given increase in global mean temperature change could be estimated for average, high and low climate sensitivity (figure 58), the existence of a limited budget means that CO_2 emissions have to be reduced to zero to stabilize the global mean temperature;

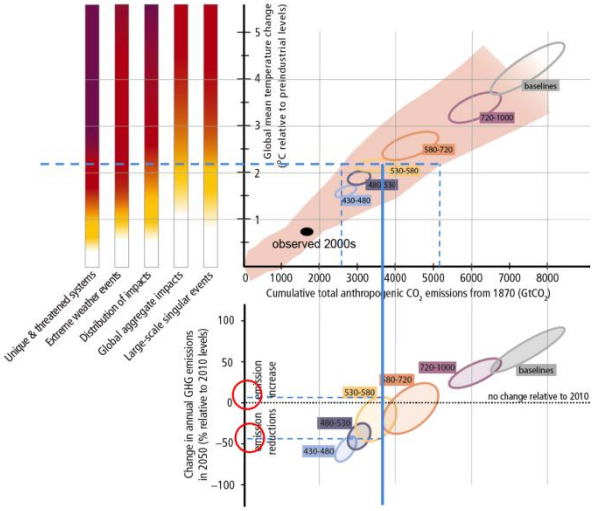
(b) In the **near term, a constraint for changes in annual GHG emissions in 2050** relative to 2010 (panel C). This constraint depends on the sensitivity of the climate response (figure 59). For example, considering high climate sensitivity the emission reductions in 2050 would be in the range of -70 to -50 per cent (see also figure 69 that shows these correlations for 2 °C warming above pre-industrial levels).

37. Mr. Hallegatte explained that figure 57 (IPCC SYR SPM.10) can also be used to determine, for a given level of reduction in the global emissions in 2050, the increases in global average temperature and the

corresponding levels of climate risks. For example, figure 59 presents these values for 10 per cent emission reductions in 2050. He added that the figure does not show the likelihood of staying below a limit temperature for any particular range for GHG concentrations in atmosphere by 2100. This is shown in SYR table SPM.1 and is discussed partially in paragraph 63.

Figure 58

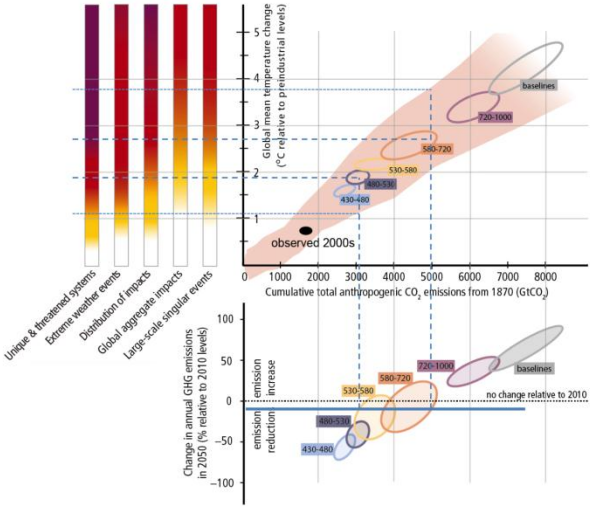
The carbon budget and the reductions in global emissions for a given level of increase in global average temperature



Source: Slide 16 of the presentation by Ms. Renate Christ (Intergovernmental Panel on Climate Change), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/sed1-revisedrc_fin.pdf>. The figure illustrates how any levels of additional risks (top left, top dashed horizontal blue line) can be connected to GHG emission changes by 2050 (red circles) considering the best estimate (solid vertical blue line) and likely range of uncertainties from non-CO_2 gases, climate, and carbon cycle (dashed vertical blue lines). Added uncertainty arises from action on non-CO_2 gases, timing of pre-2050 action, and ambition of post-2050 action.

Figure 59

The global average temperature and the corresponding levels of climate risks for a given level of emission reductions in 2050



Source: Slide 22 of the presentation by Ms. Renate Christ (Intergovernmental Panel on Climate Change), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/sed1-revisedrc_fin.pdf>. The figure illustrates how additional risks from climate change (top left, horizontal blue lines) depend on emission changes by 2050 (e.g. -10%, bottom horizontal solid blue line), but also on climate sensitivity and post-2050 action (here looking at average (dashed blue lines) and likely (thin dotted blue lines) range of climate sensitivity for ambitious (left vertical dashed blue line) and less ambitious (right vertical dashed blue line) post-2050 action).

B. Part 1: The adequacy of the long-term global goal in the light of the ultimate objective of the Convention and overall progress made towards achieving the long-term global goal, including a consideration of the commitments under the Convention based on the Synthesis Report of the Fifth Assessment Report

1. Presentations by experts

38. Mr. Hans-Otto Pörtner (IPCC) gave a presentation on the adequacy of the long-term global goal in terms of preventing unacceptable consequences for the adaptation of ecosystems and food production. He explained he would focus on Article 2 of the Convention, which contains its objective, including the stabilization of GHG concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system, and within a timeframe sufficient to allow ecosystems to adapt naturally to climate change and to ensure that food production is not threatened and economic development proceeds in a sustainable manner. He compared the affected sectors and long-term global goal with respect to key risks of impacts and avoided impacts.

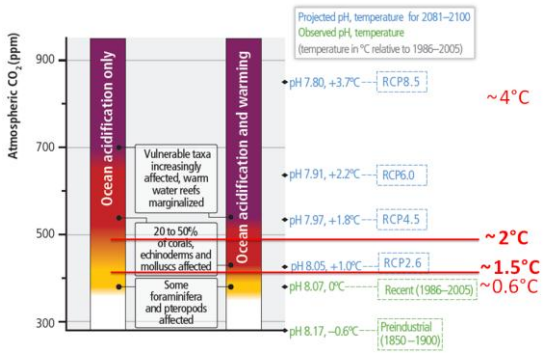
39. At the **current level of warming of 0.85 °C** above pre-industrial levels, impacts have been observed on all continents and in all oceans, including: **displacements of marine, freshwater and terrestrial species**;

constrained increases in crop production; **forest dieback due to drought and heat**; and **moderate risk from climate change to some unique systems**, which may rise if combined with other pressures. One of these systems is **warm water coral reefs**, which are under combined pressures, including the release of symbiotic algae and associated bleaching of coral due to warming. He cited the example of the Great Barrier Reef, which has already lost half of its live coral cover since 1985, due to cyclones, increased predation and bleaching.

40. With regard to **latitudinal shifts of coral reefs** he noted that, while such shifts have occurred in the last interglacial period with temperature increases of less than 1 °, coral reefs will be under additional stress from acidification constraining redistribution. Mr. Pörtner explained that marine organisms in general are increasingly under **pressure, as the oceans are warming, acidifying and losing oxygen**. He added that the combination of ocean acidification with warming increases the risk levels for marine species (figure 60). In a world 1.5 °C warmer than in pre-industrial times, we are on the verge of moving to high risk for these organisms, while in a world 2 °C warmer than in pre-industrial times, the risk already becomes high for these ecosystems. For freshwater and terrestrial species, in a world 1.5 °C warmer, most trees and herbs would be at moderate risk from falling behind the moving climate zones. However, in flat landscapes, 2 °C warming means that climate change velocity would become too high for terrestrial and freshwater organisms to follow the moving climate zones (figure 61).

Figure 60

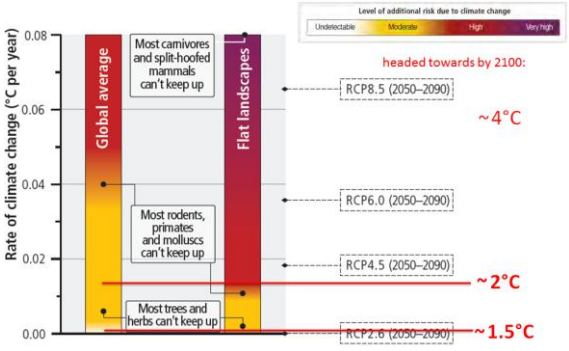
Risk for marine species impacted by ocean acidification only, or additionally by warming extremes



Source: Synthesis Report of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure 2.5, panel (B). The figure illustrates the increased risk for marine species when considering ocean acidification and heat exposure.

Figure 61

Risk for terrestrial and freshwater species impacted by the rate of warming



Source: Synthesis Report of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure 2.5, panel (A). The figure illustrates the species composition limited ability of terrestrial and freshwater ecosystems to follow the moving climate zones due to rate of warming.

41. On food security, Mr. Pörtner stated that at 2 °C of warming, **fisheries** will be under pressure from ocean warming, which will combine with the present overexploitation of stocks and with acidification and loss of oxygen. Although there is capacity to increase **crop production**, this has already been reduced because of climate change. In addition, in a world 2 °C warmer, even high adaptation will not be able to reduce risk to the currently low level.

42. He then turned to the **Arctic** summer sea ice and associated sea life, which is projected to be marginalized by mid-century in 'business as usual' scenarios. In an ambitious scenario, some of that sea ice may be preserved. As for **sea level rise**, with high mitigation and adaptation scenarios, we may limit global sea level rise to 1 m. Otherwise, sea level rise beyond 2100 may challenge natural and human systems, affecting habitat, freshwater resources and human society through flood events. He underlined that the sea level rose more than 7 m when the atmosphere had reached 400 ppm of CO_2 in the Pliocene (3–5 million years ago).

43. In concluding, he summarized the key findings of his presentation, highlighting that:

(a) In **a world 1.5 °C warmer** than in pre-industrial times: climate change velocity would be slow enough for most terrestrial and freshwater organisms to follow; up to half of coral reefs may remain intact; sea level rise may remain below 1 m; some Arctic summer sea ice may remain; ocean acidification impacts would stay at moderate levels; the capacity to increase food production would be reduced, but some scope would exist

for adaptation; some unique systems would be at high risk; and the risks of combined ocean acidification and warming would become more prominent;

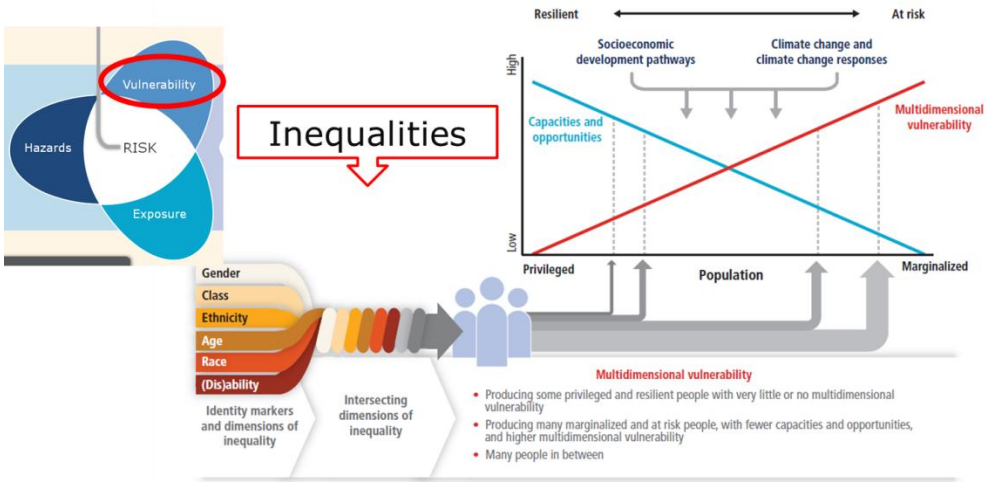
(b) In **a world 2 °C warmer** than in pre-industrial times: climate change velocity would become too high for some species to move sufficiently fast and follow their preferred temperatures; long-term sea level rise may exceed 1 m; Arctic summer sea ice may be lost; some unique systems would be at high risk; the risks of combined ocean warming and acidification would become high; and crop production would be at high risk with some potential for adaptation;

(c) In **a world 4 °C warmer** than in pre-industrial times: most projected climate risks for ecosystem would become impacts; biodiversity would be lost, and the catch potential of fisheries would be highly reduced; crop production would be at high risk; climate change velocity would be much too high for terrestrial and freshwater species to move sufficiently fast; long-term sea level rise would far exceed 1 m; Arctic summer sea ice would be lost; some unique systems would be marginalized; and the risks of combined ocean warming and acidification would become very high.

44. Ms. Petra Tschakert (IPCC) gave a presentation on the adequacy of the long-term global goal in terms of preventing the unacceptable consequences of climate change on sustainable economic development. She underlined that **sustainable economic development** can be **seen through** the lenses **livelihoods, food security, and economics**, and **is not only an outcome of climate change, but also shapes vulnerability to climate change**.

45. Differences in vulnerability and exposure to climate change arise from non-climatic factors and from multi-dimensional inequalities, which are often produced by uneven development processes. Development shapes inequalities and these inequalities shape differential risks from climate change (figure 62). **People who are socially, economically, culturally, politically, institutionally or otherwise marginalized are especially vulnerable to climate change** owing to multidimensional vulnerability, as well as owing to lack of capacities and opportunities for adaptation (right-hand side of figure 62).

Figure 62
Multi-dimensional inequalities



Source: Slide 3 of the presentation by Ms. Petra Tschakert (Intergovernmental Panel on Climate Change (IPCC)), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/sed4_tschakert_2.pdf>. The figure illustrates that multidimensional vulnerability is driven by intersecting dimensions of inequality, socioeconomic development pathways, and climate change and climate change responses (see also contribution of Working Group II to the Fifth Assessment Report of the IPCC, figure 13.5).

46. Ms. Tschakert stated that **climate-related hazards exacerbate other stressors**, such as socio-economic and environmental stressors, and have a negative impact on people and livelihoods, with the emergence of critical thresholds, when **all stressors converge**.

47. Regarding **future risks**, she noted that: climate change will amplify existing risks and create new risks for natural and human systems; risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development; and increasing magnitudes of warming increase the

likelihood of severe, pervasive and irreversible impacts for people, species and ecosystems. She pointed to those risks that are relevant to sustainable development, such as ill health, water insecurity, service and infrastructure, violent conflicts or poverty traps (see figure 56 for representative key risks and the potential for adaptation for human and managed systems in various regions).

48. Ms. Tschakert then detailed the RFC, with a focus on human and managed systems. **At the current 0.8 °C of warming** above pre-industrial levels, aggregated risks to **unique and threatened systems** indicate that indigenous people or other unique communities of peoples, such as Arctic communities and the Bolivian highlands, are already impacted by climate change.

49. For a **level of warming of 2 °C** above pre-industrial levels:

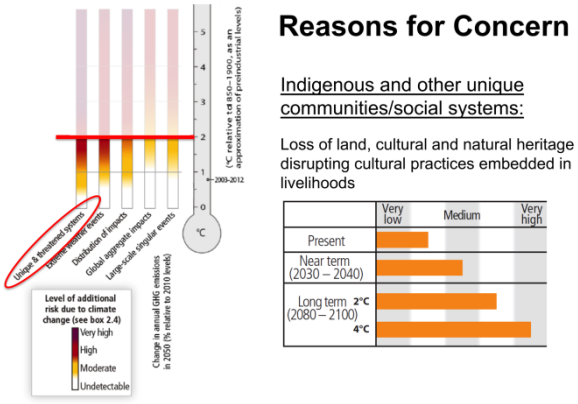
(a) Unique and threatened systems: many more moderate and high risks would emerge; indigenous people would be at risk of the loss of land, cultural and natural heritage; and cultural practices embedded in livelihoods would be disrupted (figure 63).

(b) **Extreme weather events:** high risks would exist for megacities in relation to the urban heat island effect, air pollution and differential vulnerabilities; urban housing and human health; displacement and permanent migration; livelihood struggles and conflict in resource-dependent livelihoods, such as agriculture and pastoralism; and high livelihood damage. She emphasized that 'trapped' populations are more vulnerable to environmental change because of their inability to move (figure 64, right-hand side of the figure);

(c) **Distribution of impacts**: she stressed that risks are increasingly unevenly distributed, affecting in particular: low-latitudes and low-income countries; shifts from transient to chronic poverty, and related social marginalization and food insecurity; and the elderly, children, the socially marginalized and outdoor workers, who are disproportionally at risk from heat stress;

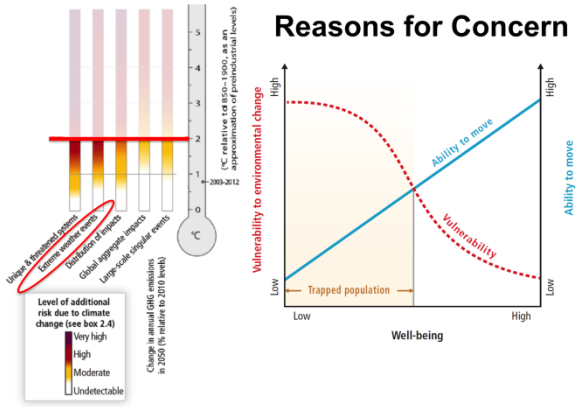
(d) **Global aggregate impacts**: she underscored that while aggregate economic damages are quite moderate, these aggregates mask impacts across sectors and regions. She explained that the poor "are too poor to come up in the statistics" as they do not make a dent in the economic analysis. The evaluations are therefore incomplete, in part because they do not take into account large-scale singular events.

Figure 63
Reasons for concern due to impact on unique and threatened systems at 2 °C of warming



Source: Slide 8 of the presentation by Ms. Petra Tschakert (Intergovernmental Panel on Climate Change), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/sed4_tschakert_2.pdf>. The figure shows the level of additional risk due to climate change for large and unique systems, at 2 °C of warming above pre-industrial levels.

Figure 64
Reasons for concern due to extreme weather events at 2 °C of warming



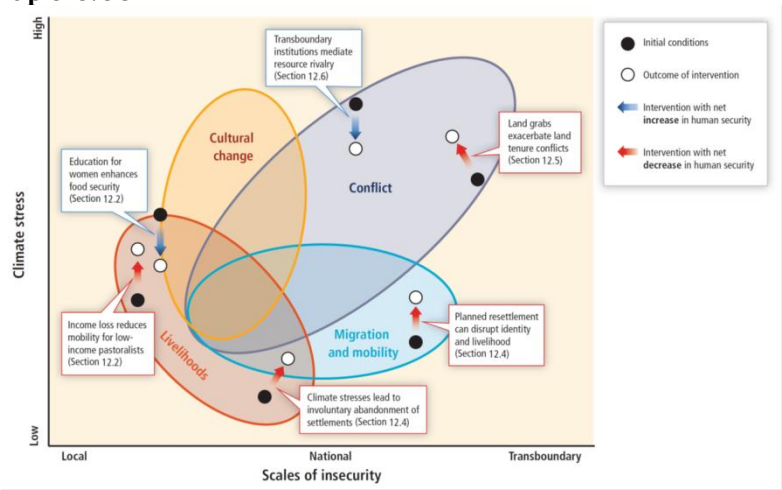
Source: Slide 10 of the presentation by Ms. Petra Tschakert (Intergovernmental Panel on Climate Change), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/sed4_tschakert_2.pdf>. The figure illustrates the level of additional risk due to climate change for extreme weather events, at 2 °C of warming above pre-industrial levels.

50. For a **level of warming of 3 °C** above pre-industrial levels, she mentioned limits to adaptation in relation to: urban water supply systems, heat-sensitive people, productivity, food security and the loss of cultural identity. In particular, she referred to the declining adaptation potential in case of conflict over land acquisition and displacement. There are few estimates of the economic costs of a **warming of 3 °C** above pre-industrial levels.

51. Ms. Tschakert emphasized the multiple interactions between climate stress and the scale of insecurity at the local, national and transboundary levels, highlighting the effects of, for example, income loss on mobility, education of women on food security, and planned resettlements on livelihoods (figure 65).

52. In concluding, she emphasized that: **climate change is a threat to equitable and sustainable development**; averages and aggregates mask disproportional impacts and risks; critical thresholds for communities and society exist and are not visible from a global average; critical thresholds of climate stressors in combination with other stressors exacerbate livelihood struggles, especially among disadvantaged people; **a possible yardstick to assess the level of risk would be the transition from acceptable to unacceptable at the local level**; and **limiting the effects of climate change is necessary to achieve sustainable development and equity, including the eradication of poverty**.

Figure 65
Interactions at multiple levels



Source: Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure 12.3. The figure shows the synthesis of evidence on the degree of impacts of climate change (climate stress) and scales of human security as they interact for livelihoods, culture, migration, and conflict.

53. Mr. Chris Field (IPCC) and Mr. Ottmar Edenhofer (IPCC) delivered a joint presentation on the adequacy of 2 °C in terms of risk management within planetary boundaries and progress towards the long-term global goal.

54. Mr. Field introduced the concept of a '**black elephant'**, which was described in an editorial by Mr. Thomas Friedman published in the *New York Times*. A 'black elephant', he explained, is a cross between a 'black swan', i.e. an unlikely, unexpected event with enormous ramifications, and the 'elephant in the room,' i.e. a problem that is visible to everyone, but that no one wants to address, even though we know that one day it will have vast, black-swan-like consequences. Mr. Field explained that climate change is a 'black elephant' problem as it combines: black swan risks, such as the collapse of the Antarctic ice sheet, which is a low-probability, high-impact event; and the elephant in the room, since it involves some elements that are difficult to assess, such as human population size, weak institutions and poor governance, inequality in income that marginalizes people, etc.

55. Ms. Katharine Mach (IPCC) briefly explained the concept of climate risks as introduced in the contribution of WGII to the AR5 (figure 66). She outlined key risks and the assessment of risks at present, near-term (approximately equivalent to a warming of 1.5 °C), and long-term (at 2 °C and 4 °C) with current and high adaptation. She also restated the WGII findings that an increasing magnitude of warming increases the likelihood of severe and pervasive impacts.

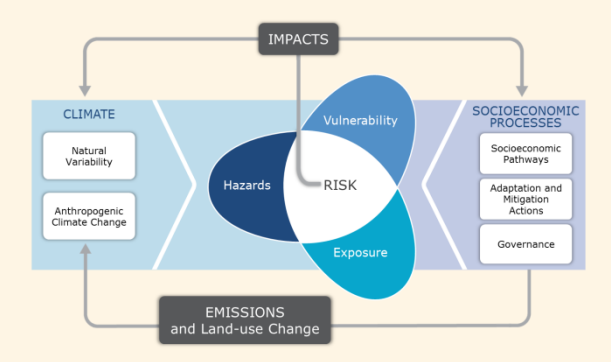
56. Ms. Mach stated that WGII assessed 102 key risks with low and high levels of adaptation. The SYR features 25 key risks across the regions of the world (see figure 56 for representative key regional risks). These risks are tied to physical, biological and human systems. She then introduced the concept on '**one unit of risk**', as being the transition of a risk from one level to the next (e.g. from very low to low or from medium to medium-

high). Noting that, using such a concept, **some 0.5 additional units of risks were estimated at 2 °C of warming above pre-industrial levels compared with 1.5 °C**, she stressed that for the latter, there is more scope for adaptation (figure 67). This type of analysis could extract additional information across regions and sectors for these two levels of global warming.

57. Ms. Mach pointed to an important caveat: the **near-term (2030–2040) and 2 °C in 2080–2100 are not strictly comparable**; some non-climate trends exacerbate risks; some non-climate trends moderate risks; and the risk assessment was not conducted by WGII for comparing the 1.5 °C and 2 °C targets. Mr. Field added that the **IPCC did not systematically assess risks due to warming levels between 1.5 °C and 2 °C above pre-industrial levels** owing to a lack of information, yet an analysis of the comparison between 1.52 °C and 2 °C shows that there are **consistent differences of about half of a risk unit or more**. In the light of the difficulty of predicting the black elephant risk, there is a value in **taking a precautionary approach and adopting a more stringent target**. Mr. Field underscored that across the risk analysis, investments in adaptation and the propensity for risk reduction are at risk of being overwhelmed.

Figure 66

Illustration of the core concept of Working Group II in the Fifth Assessment Report



Source: Summary for policymakers in the contribution of Working Group II (WGII) to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change, figure SPM.1. The figure illustrates the constituents of risk being a combination of climate hazards, vulnerability, and exposure – the fundamental concept used throughout AR5 by WGII.

Figure 67

Reasons for concern due to extreme weather events at 2 °C of warming

Regional Key Risk Map
25 Key Risks

	Key Risks Assessed	Risk at 2°C > Risk 2030-2040 (current adaptation)	Risk at 2°C > Risk 2030-2040 (high adaptation)
Physical Systems	11	0.6	0.6
Biological Systems	5	0.7	0.7
Human Systems	9	0.6	0.6

Global, Regional, and Sectoral Key Risks in WGII Report
102 Key Risks

	Key Risks Assessed	Risk at 2°C > Risk 2030-2040 (current adaptation)	Risk at 2°C > Risk 2030-2040 (high adaptation)
Physical Systems	14	0.6	0.6
Biological Systems	27	0.3	0.4
Human Systems	61	0.6	0.5

Source: Slide 6 of the presentation by Ms. Katharine Mach (Intergovernmental Panel on Climate Change), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/field_for_sed_12-2014.pdf>. The figure shows the increase in risks for key, global, regional and sectoral risks at 2 °C of warming above pre-industrial levels, with current and high adaptation (expressed in units of risks).

58. Mr. Edenhofer focused on a future pathway for adaptation, mitigation and sustainable development. In this context he emphasized that: (i) the **optimal balance among mitigation, adaptation and residual impacts cannot be determined with current knowledge**; (ii) **risks from adaptation and mitigation can be identified and managed through appropriate mitigation and adaptation measures**; and (iii) **mitigation and adaptation are complementary approaches for reducing climate change impacts over different timescales**.

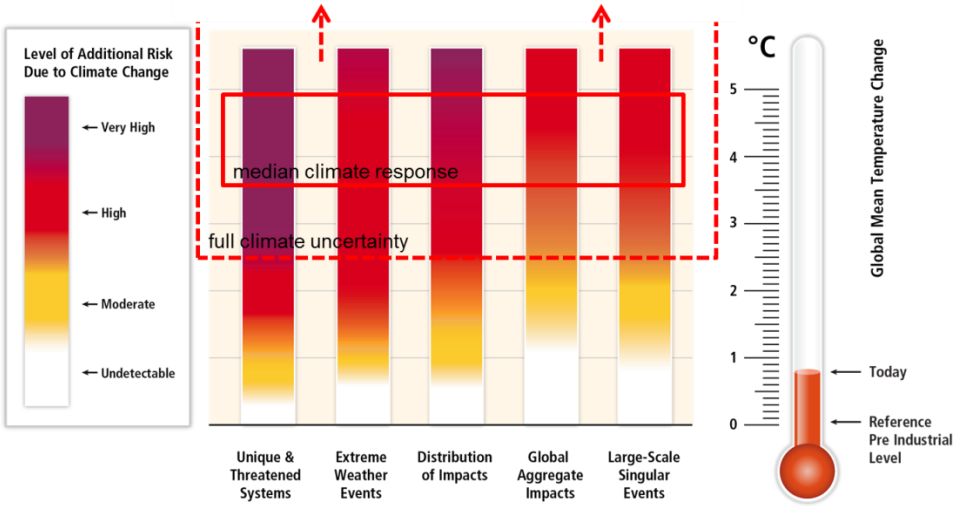
59. Mr. Edenhofer added that if current emissions trends continue, even with adaptation, warming by the end of the twenty-first century will lead to high to very high risk of severe, widespread and irreversible impacts globally. Figure 68 shows these risks for a range of temperature increases corresponding to a 'business as usual' scenario and a median climate response. He then noted that, considering the full climate uncertainty, the minimum temperature increase might be lower, but the maximum temperature increase might also be much higher and significantly beyond what was assessed by IPCC (figure 68, top red arrows).

60. Mr. Edenhofer then explained that the IPCC explored the implications of a world warmer by 4 °C and 2 °C above pre-industrial levels, noting that the **1.5 °C limit is similar to the 2 °C one, but calls for additional scaling up of the challenging features** (see also paragraph 66).

61. Substantial cuts in GHG emissions over the next few decades, which would limit global warming below 2 °C, can significantly reduce risks of climate change by limiting warming in the second half of the twenty-first century and beyond (figure 68, risks at a 4.7 °C level of warming above pre-industrial levels compared with a

2 °C warming). Mr. Edenhofer stressed that mitigation action has co-benefits, but also risks. However, the **risks of mitigation do not involve the possibility of severe, widespread and irreversible impacts, as do the risks from climate change impacts**. He added that stabilization of atmospheric concentrations requires moving away from the baseline, or the 'business as usual' scenario, even for a less ambitious mitigation goal.

Figure 68
Climate risks for 'business as usual' scenarios



Source: Slide 2 of the presentation by Mr. Ottmar Edenhofer (Intergovernmental Panel on Climate Change), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141202_sed_edenhofer_lima_final4.pdf>. The figure shows the level of risks associated with reasons for concern without additional mitigation efforts beyond those in place today, and even with adaptation. Mr. Ottmar Edenhofer emphasized the uncertainties contained in these risk estimates, if fully considered mean possibly lower risks (bottom horizontal dashed line) but also very much higher risks (top red arrows) that even reach beyond what was assessed by IPCC.

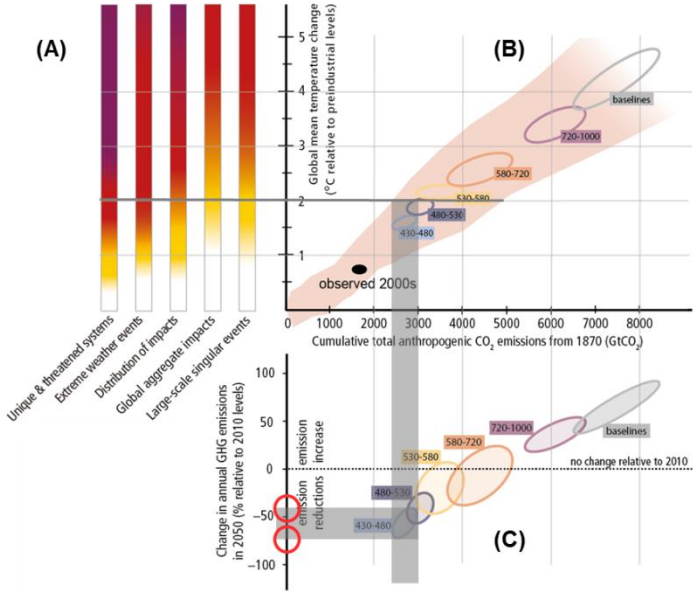
Abbreviation: BAU = business as usual

62. Mr. Edenhofer emphasized that cumulative emissions of CO_2 will largely determine global mean surface warming by the late twenty-first century and beyond. Limiting risks across RFC would imply a limit for cumulative emissions of CO_2. He underscored that the IPCC had found with high confidence that such a limit would require that **global net emissions of CO_2 decrease to near zero or below by 2100** and would constrain annual emissions over the next few decades. He cautioned, however, that some risks from climate damages are unavoidable, even with mitigation and adaptation.

63. Mr. Edenhofer then illustrated how figure SPM.10 of the AR5 SYR could be used to determine the reductions in **global emissions by 2050 needed to limit global warming to 2 °C, with a likely** probability. Considering the 430–480 category of scenarios in figure 69, this indicates an emission reduction range of **40–70 per cent in 2050 compared with 2010 levels**, clarifying that use of CO_2 **removal technologies will be much more needed for a 40 per cent than a 70 per cent reduction.**

Figure 69

The relationship between risks from climate change, temperature change, cumulative carbon dioxide emissions and changes in annual greenhouse gas emissions by 2050 for 2 °C warming

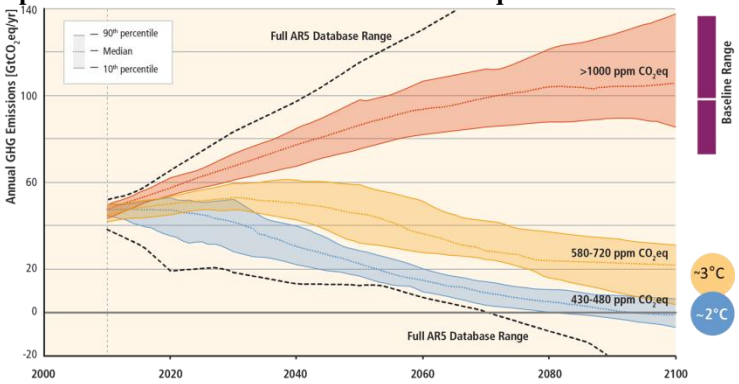


Source: Slide 6 of the presentation by Mr. Ottmar Edenhofer (Intergovernmental Panel on Climate Change), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141202_sed_edenhofer_lima_final4.pdf>. The figure shows the relationship among risks from climate change (panel A), temperature change and cumulative CO_2 emissions (panel B), and changes in annual GHG emissions by 2050 (panel C), here illustrating a 2 °C of warming above pre-industrial levels (horizontal grey line) that corresponds to a 40 per cent to 70 per cent reduction in GHG emissions by 2050 (red circles) while implying a GHG concentration of 430–480 ppm CO_2 equivalent in 2100 through suitable post-2050 action.

64. With regard to **stabilization of atmospheric concentrations**, he stressed that this requires moving away from the baseline, regardless of the mitigation goal (figure 70). Both the scenarios for limiting global warming below 2 °C and below 3 °C require a fundamental departure from the 'business as usual' scenario and, in the short term, similar global emission reductions are needed. Scenarios leading to 1.5 °C warming (being consistent with the lowest range of the blue strip) would require more negative emissions.

Figure 70

Stabilization of atmospheric concentrations of carbon dioxide equivalent



Source: Slide 7 of the presentation by Mr. Ottmar Edenhofer (Intergovernmental Panel on Climate Change), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141202_sed_edenhofer_lima_final4.pdf>. The figure shows the GHG emission pathways up to 2100 for a 'business as usual scenario' (red), and for 3 °C (yellow) and 2 °C (blue) of warming above pre-industrial levels.

Abbreviation: GHG = greenhouse gas.

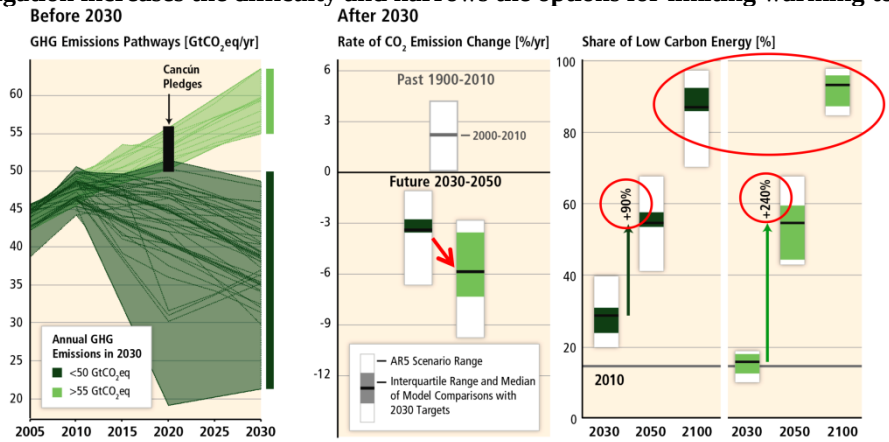
65. Mr. Edenhofer highlighted the increased challenges of delayed mitigation pathways – particularly between 2030 and 2050. He stressed that **immediate action** before 2030 would widen options for multiple cost-effective mitigation pathways (figure 71, left-hand side panel) that are characterized by average annual CO_2 emissions reductions of about 3 per cent (middle panel) and would require roughly a doubling of the share of low-carbon energy technologies between 2030 and 2050 (right-hand side panel). **Delaying mitigation** increases the difficulty and narrows the options for limiting warming to 2 °C above pre-industrial levels. Scenarios with delayed mitigation action that can still achieve the 2 °C limit require a more ambitious mitigation profile after 2030. Average annual CO_2 emission reduction requirements increase to about 6 per cent between 2030 and 2050, and the share of low carbon energy technologies need to be more than tripled, which has significant risks. In this context, he emphasized that for reaching the 2 °C limit the Cancun pledges are only consistent with emission pathways that show such increased mitigation challenges.

66. **On the 1.5 °C limit**, he underscored that scientific evidence remains limited. While recognizing that a comprehensive assessment of this limit is difficult in the absence of multi-model comparison studies and with the overall limited number of studies, he outlined four characteristics of the existing studies of this limit, namely: (i) temperature overshoot and large-scale application of CO_2 removal technologies; (ii) immediate mitigation action; (iii) rapid scaling up of the full set of technologies; and (iv) the development along a low-energy demand pathway.

67. **On the costs of mitigation**, Mr. Edenhofer stated that although cost estimates vary significantly, they do not strongly affect global gross domestic product (GDP) growth; therefore, climate policy can be reconciled with economic growth. Global costs rise with the ambition of the mitigation goal.

Figure 71

Delaying mitigation increases the difficulty and narrows the options for limiting warming to 2 °C



Source: Slide 13 of the presentation by Mr. Ottmar Edenhofer (Intergovernmental Panel on Climate Change), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141202_sed_edenhofer_lima_final4.pdf>. The figure summarizes the implications of greenhouse gas emission levels in 2030 (left) for the subsequent rates of CO_2 emission reductions (middle) and scaling-up of low-carbon energy (right) needed for mitigation scenarios reaching 450–500 ppm by 2100 comparing Cancun Pledges (light green) with more ambitious mitigation actions by 2030 (dark green).

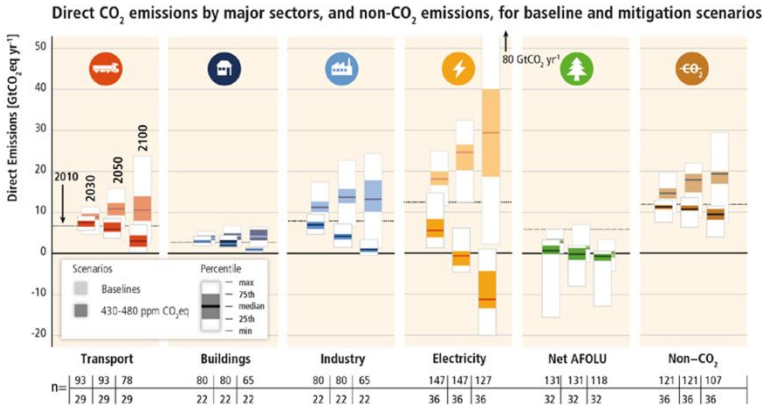
Abbreviation: GHG = greenhouse gas

68. In concluding, he emphasized that climate change is a global commons problem, which requires international cooperation and coordination. He stressed that for the twenty-first century, the limiting factor is not the amount of fossil fuel in the ground, but the limited disposal space in the atmosphere, which is why low-stabilization pathways are so demanding in terms of technological and institutional requirements.

69. Mr. Ramón Pichs-Madruga (IPCC) presented key findings summarized in the AR5 SYR on climate policies, technologies and finance. He emphasized that the previous presentations had shown that: a combination of adaptation and substantial and sustained mitigation can limit climate change risk; there are important technological, economic, social and institutional challenges related to climate response; and delaying mitigation will substantially increase challenges and costs related to limiting warming. He emphasized that **well-designed systemic and cross-sectoral mitigation strategies are more cost-effective in cutting emissions than a focus on individual technologies and sectors** (figure 72).

Figure 72

Cross-sectoral mitigation strategies are more cost-effective than a focus on individual technologies or sectors



Source: Summary for policymakers of the Synthesis Report of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure SPM.14. The figure shows CO_2 emissions by sector and total non-CO_2 greenhouse gas emissions (Kyoto gases) across sectors for the baseline (faded bars) and mitigation scenarios (solid-colour bars) by 2030, 2050, and 2100 that reach about 450 ppm CO_2 eq concentrations in 2100.

Abbreviation: GHG = greenhouse gas

70. Emphasizing that **adaptation and mitigation are complementarity response strategies**, Mr. Pichs-Madruga said substantial emission reductions over the next few decades could reduce climate risks in the twenty-first century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the long term, and contribute to climate-resilient pathways for sustainable development.

71. He added that while many adaptation and mitigation options can help address climate change, **no single option is sufficient by itself**. He listed common enabling factors that underpin adaptation and mitigation responses: effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods, and behavioural and lifestyle choices.

72. He emphasized that limiting the effects of **climate change** is necessary to achieve **sustainable development and equity, including poverty eradication**. He pointed out that countries' past and future contributions to the accumulation of GHGs in the atmosphere are different. Countries also face varying challenges and circumstances, and have different capacities to address mitigation and adaptation.

73. Mr. Pichs-Madruga then addressed the questions of **equity, justice and fairness** related to climate change responses, such as those related to the fact that: many of those most vulnerable to climate change are those who have contributed the least to this challenge; delaying action shifts the burden to future generations; insufficient adaptation responses to emerging impacts are already eroding the basis for sustainable development; and evidence suggests that outcomes seen as equitable can lead to more effective cooperation. He stated that cooperative responses, including international cooperation, are therefore required to effectively mitigate GHG emissions and address other climate change issues. Furthermore, he emphasized that the effectiveness of adaptation can be enhanced through complementary actions across levels, including international cooperation.

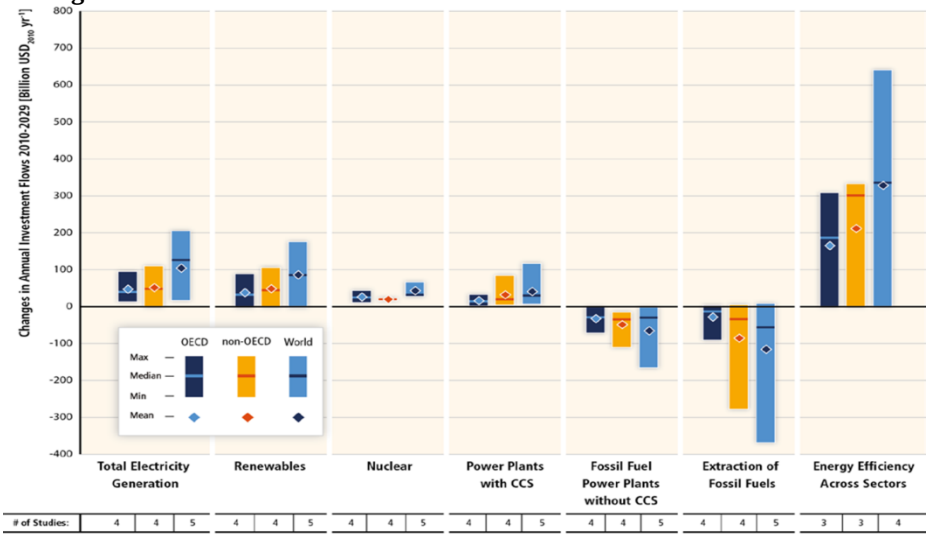
74. On **policies, technologies and finance**, Mr. Pichs-Madruga stated that effective adaptation and mitigation responses will depend on policies and measures across multiple scales: international, regional, national and subnational. Policies across all scales, supporting technology development, diffusion and transfer, as well as finance for responses to climate change, can complement and enhance the effectiveness of policies that directly promote adaptation and mitigation. Substantial reductions in emissions would require large changes in investment patterns (figure 73).

75. In concluding, Mr. Pichs-Madruga focused on the relationship between climate change responses and sustainable development, emphasizing that comprehensive strategies in response to climate change that are consistent with sustainable development take into account the co-benefits, adverse side-effects and risks that may arise from both adaptation and mitigation options. He stressed that the IPCC found with high confidence that there are many opportunities to link mitigation, adaptation and the pursuit of other societal objectives through

integrated responses. The IPCC also found with medium confidence that successful implementation relies on relevant tools, suitable governance structures and enhanced capacity to respond.

Figure 73

Change in annual investment flows from the average baseline level over the next two decades for 430–530 ppm mitigation scenarios



Source: The Synthesis Report of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, figure 4.4. The figure shows change in annual investment flows from the average baseline level over the next two decades (2010 to 2029) for mitigation scenarios that stabilize concentrations (without overshoot) within the range of approximately 430–530 ppm CO_2 eq by 2100.

Abbreviations: CCS = carbon capture and storage; OECD = Organisation for Economic Co-operation and Development.

2. General discussion

76. The ensuing discussion was guided by the following questions on theme 1 of the review:

(a) What are the salient messages from the AR5 SYR relevant to the 2013–2015 review? What are the strategies for risk reduction and for managing adaptation and mitigation? What is the relationship among risks of climate change, cumulative CO_2 emissions and annual GHG emissions over the next decades?

(b) How does the AR5 contribute to operationalizing Article 2 of the Convention, including with regard to anthropogenic interference with the climate system and associated risks or dangers to food production, sustainable economic development and ecosystem adaptation? How do these risks grow as we move from 1.5 °C to 2 °C of global warming? What does the AR5 SYR tell us about limiting global warming to 2 °C?

77. Mr. Fischlin suggested Parties focus on how the SED operationalizes Article 2 of the Convention, and addressed questions such as: what does dangerous interference mean? If value judgment has to be introduced to determine the acceptability of risk, how adequate is the long-term global goal? By when, and by how much, do we have to mitigate and foster adaptation? Are there barriers or enablers we should pay attention to?

78. A Party welcomed the **comparison of impacts between 1.5 °C and 2 °C** of warming above pre-industrial levels. She asked **why in aggregate there is only a one half point increase in risk between a 50 per cent** (at 1.5 °C) **and a complete loss** (at 2 °C) **of coral reefs**. The expert clarified that he was talking about a marginalization of coral reefs, not their total disappearance, and the degree of this marginalization. Some organisms may not become completely extinct but may not to be able to provide the services they are currently providing. He added that this can mark a difference between the local and the global views, as the degree of risk change between 1.5 °C and 2 °C may be much greater for the affected regions than at the global level.

79. One Party noted that "we are already facing a lot of trouble", emphasizing that even at 1.5 °C of warming above pre-industrial levels, risks to unique and threatened systems are assessed as high. He added that climate impacts are catastrophic for his country, and that **qualifying the risks related to the distribution of impacts as "moderate" is not convincing**. An expert explained that in the regional chapter of AR5 (the Oceans and

Australasia), the IPCC has assessed the risks to coral reefs as high in the near term and very high for the two regions in the long term at 2 °C of warming, emphasizing the regional differences in the assessment of risks to these ecosystems. In response to a request for clarification on the level of risk associated with the distribution of impacts, the expert explained that the level of risk is related to the number of causal links that the IPCC was able to assess in developing the RFC. For a given country, coral reefs may be essential to the lifestyle pursued, but the IPCC would not be able to make the necessary connections because the assessment is not carried out at that level. Furthermore, the analysis does not allow characterizing every possible combination of risks that has potential impacts.

80. One Party commented that we know from WGI that for representative concentration pathway (RCP) scenario 2.6 of the IPCC the mean increase in temperature at the end of the century will be 1.6 °C (0.9–2.3 °C) and for scenario RCP4.5 2.4 °C (1.9–4.2 °C). Given the overlaps between these temperatures, he asked how the **differential level of impacts for 1.5 °C and 2 °C of warming can be quantified with any level of certainty**, and **what the scientific community needs for more certainty in the next assessment cycle of the IPCC for a more accurate result in terms of differential impacts**. An expert replied by emphasizing the importance of the caveat mentioned in his presentation on the different timeframes of impacts. He explained that WGII "took a cut" at specific examples where risk levels could be ascertained for a warming of 1.5 °C and 2 °C above pre-industrial levels. He added that there are currently few examples in the literature to characterize risks between these two levels of warming, and that WGII made some extensions beyond the published literature. For future assessment, the scientific community needs to focus more on differential impacts. He stressed that at the present stage, we have few examples and some interesting conceptual links that suggest the differences, but they are only documented in a few cases.

81. On Ms. Tschakert's presentation, one Party asked about the **impacts of climate change on poverty reduction** and, quoting chapter 13 of the WGII report, he stated that climate change is expected to slow down economic growth and make poverty reduction more difficult for a warming of 2 °C, in particular in vulnerable countries. He then asked for a confirmation that a warming of 2 °C represents a substantial threat to the sustainable development of most the vulnerable countries. In response, the expert confirmed this finding of the WGII report.

82. Another Party asked if literature published after the IPCC cut-off dates on the **possible collapse of the West Antarctic Ice Sheet** may alter the assessment of the IPCC in relation to the risk of this large-scale singular event. An expert replied that it is too early to draw conclusions as there is no assessment of this literature yet. Another expert added that the current understanding is insufficient to make the assessment, and that the AR5 findings would not change with the few articles published after March 2013.

83. One Party asked the **extent to which risk can be reduced through adaptation**, noting that **other stressors also impact vulnerability and exposure**, such as socioeconomic pathways and governance. An expert responded that some risks have a lot of space for adaptation, while others have little. Key risks that have less adaptation potential relate to ecosystems where human interventions lead to reaching a limit, or when a relatively low physical or biological boundary was reached. Those are areas where addressing vulnerability or exposure has little prospect to make a difference. He added that assessing prospects for adaptation is still "a very imprecise science".

84. One Party asked, in the context of the options for staying under 2 °C of warming and of global GHG emissions approaching zero or below zero in 2100 for scenarios limiting warming below 2 °C, **what will be the pathways for non-CO_2 emissions**. He also asked how agricultural emissions and non-CO_2 gases should be considered when determining the desired level of emissions in 2100. An expert explained that although reducing non-CO_2 emissions can be an important element of mitigation strategies, the cumulative budget of CO_2 emissions determines the temperature, and long-term warming is mainly driven by CO_2 emissions.

85. In response to a question by one Party on how the IPCC is emphasizing the role of **indigenous knowledge** in adaptation, an expert stressed that while adaptation can relate to infrastructure, there are other approaches to adaptation such as structural institutional and social measures (see table SPM.1 of AR5 WGII). Among social measures, there are specific adaptation measures referring to learning and knowledge sharing, with use of indigenous knowledge and participatory action. She added that the IPCC emphasized the importance of a co-production of knowledge that includes indigenous knowledge. Another expert underlined that, to date, the application of indigenous knowledge has been "spotty".

86. One Party noted the need for a process to assess progress towards the long-term global goal, and asked how one should consider the adequacy of the long-term global goal in the light of **past and present contributions**. He suggested assessing the adequacy of the long-term global goal, including long-term perspectives, based on **a temperature increase approach**, and considering past and future contributions. One expert underscored that the IPCC provided information consistent with its mandate, and cannot go beyond this mandate to determine what the long-term goal should be or how to translate this goal into risks. Another expert added that the IPCC cannot make a value judgment related to historical responsibility. He pointed to the AR5 chapter on historical emissions, ethical issues and equity. On the choice of appropriate metrics and the global warming potential, he explained that the IPCC has evaluated the pros and cons of various metrics, referring to chapters 2, 3 and 6 of the contribution of WGIII to the AR5.

87. The ensuing discussion was guided by the following questions on theme 2 of the review:

(a) We heard from the IPCC that increasing magnitudes of warming will increase severe, widespread and irreversible impacts of climate change. In the light of this, what are the risks assessed by your organization on human health, food production and other ecosystem services at a 2 °C or 1.5 °C level of global mean warming compared with pre-industrial levels, and how does your organization contribute to reducing and managing these risks?

(b) What is the gap between current mitigation and adaptation efforts and those required to achieve the long-term global goal as characterized by a 2 °C or 1.5 °C level of warming relative to pre-industrial levels? How can this gap be bridged?

(c) What policy options has your organization identified for the decarbonization of the energy system called for by pathways consistent with limiting warming below 1.5 °C or 2 °C compared with pre-industrial levels? What are the economic and technological risks associated with this decarbonization?

(d) How effective have the steps taken by your organization been in terms of supporting national activities aimed at minimizing the impacts of climate change? What barriers have your organization encountered and how has it succeeded in overcoming them?

(e) Which policies and measures has your organization identified as effective to bridge the emissions and adaptation gap, and how can these policies and measures be emulated?

88. One Party asked if the information presented came from the various contributions of the Working Groups, or only from the SYR. Pointing to **differences between the carbon budget and emission reductions for remaining under 2 °C of warming presented by WGI** (14–96 per cent in 2050 below 1990) **and WGIII** (40–70 per cent in 2050 below 2010). He also asked how this information can be used for decision-making. An expert clarified that the requirement to reduce emissions by 40–70 per cent by 2050 to reach the long-term global goal is to be read with the "cost effectiveness" qualifier. He added that the main difference between WGI and WGIII findings comes from the fact that WGIII focused on cost-effective emission reduction profiles while considering explicitly societal uncertainties, such as delaying actions or availability of technologies. Another expert clarified that the uncertainty range (14–96 per cent in 2050 below 1990 with median 50 per cent) shown in the figures presented by WGI is related to the uncertainty in geophysical response and is based on the assessment of one scenario (scenario RCP2.6). While these uncertainties are taken into account in the assessments reported in the SYR, WGIII and the SYR further report an uncertainty range (40–70 per cent in 2050 below 2010) that is based on scenario and societal uncertainties while considering cost effectiveness. Further hedging against the geophysical uncertainty range reported by WGI would then imply deeper emission reductions by 2050 than those ranges currently reported by WGIII.

89. The same Party also asked **why observed impacts of climate change were not presented at this meeting** and if IPCC experts had presented graphics showing the amount of emissions of countries according to different development levels. An expert indicated that there is no slide on impacts that have already occurred, although these are relevant to the assessment of future risk, but these are changes that occurred at global warming of less than 1 °C. Further, he noted that the set of impacts that have been attributed so far to climate change is strongly constrained by the available studies. Another expert said no graphics relating to different levels of development had been presented.

90. **On managing risk**, one expert explained that it involves **reducing vulnerability and exposure** through, for example, human development, increasing livelihood security, poverty alleviation, ecosystem management or disaster risk reduction.

91. One Party asked **how the assessment of the RFC on distribution of impacts could be moderate if climate risks for Africa in the regional chapter are assessed as high or moderate**. An expert explained that RFC are an average or an aggregate of risks, and do not refer to any specific region. She pointed to the AR5 chapter on Africa, which confirms that any regional summary cannot be captured in the global summary because of the strong regional and sectoral differences (the aggregate level masking regional and sectoral differences) (see also para. 49 and 52 above).

92. One Party referred to the mapping of cumulative CO_2 emissions, commenting that about 275 Gt CO_2 could be further emitted while limiting temperature rise to 1.5 °C, which according to their calculation would mean that **only 7.9 years of emitting GHGs at current levels remains**. One expert said that when the temperature bar is lowered, there is a double change: more action is required to reduce emissions sooner, and more action is needed to achieve negative emissions. The calculation of the number of years of emissions disregards the possibility to have negative emissions, and makes the challenge seem greater than it probably is. The same Party then asked about the likelihood of achieving such negative emissions. One expert underscored that WGIII presents scenarios without likelihoods and that achieving negative emissions is an underlining requirement for 1.5 °C stabilization pathways. He added that if some technology is not yet available, the IPCC drew the consequences in terms of increased costs and of the feasibility of limiting warming. Another expert underlined that some technologies can come with trade-offs on land use, and that the scenarios also depend on the choices made regarding these trade-offs, not only on the availability of technologies.

93. One Party asked about the **practicality of achieving negative emissions at the end of the century**. He also queried whether making no assumptions on this practicality would affect the scenarios. An expert responded that achieving negative emissions depends on costs, trade-offs and the feasibility of various scenarios. He stated that WGIII did not come up with a conclusion regarding trade-offs, including on biodiversity, as it is up to decision makers to take into account factors related to bioenergy, which are outlined in an annex to the WGIII report. If bioenergy with CCS is not available (BECCS), mitigation costs increase. Furthermore, the more stringent the target, the more one needs to rely on other carbon removal technology. With respect to energy supply, the most risky part related to the technology availability of CCS relates to storage technologies, which have not been assessed in detail. Another important element is the fact that if CCS is available, agriculture emissions reductions can be more moderate. If BECCS is not available at a large scale, the land use and forestry sector has to make a larger contribution to the mitigation effort.

94. One Party asked about the **global costs associated with adaptation and loss and damage**, and if an assessment of the **costs of MOI** had been carried out. An expert underlined the difficulty of distinguishing between the costs of adaptation and the costs of residual impacts. He added that directly comparing the cost figures in WGII and WGIII reports would be "very misleading", since the cost of climate change in WGII is for limited warming (2 °C), i.e. for scenarios in which ambitious mitigation takes place, at a cost. So mitigation and climate change costs need to be added, more than compared. Moreover, these two estimates have their limits and problems, and should be used with care. The IPCC consensus is that these numbers are insufficient to determine the appropriate objective of global climate policy.

95. One Party commented that in order to consider the adequacy of the long-term global goal, one needs to consider at least three aspects, namely **risks at a certain temperature goal**, **avoided impacts** that would be achieved and the **feasibility** of this long-term global goal. She requested a clarification as to why he had used scenario RCP2.6 to identify the impacts of 1.5 °C of global warming, considering that this scenario was usually representative of the 2 °C limit. She added that there is limited likelihood of achieving the 1.5 °C limit. The expert explained that he used scenario RCP2.6 because it is the closest to 1.5 °C limit, despite exceeding it. The expert added that he also based the presented findings on other scenarios and sources, not only using scenario RCP2.6 based data. Another expert added that WGI provided a likely range for each scenario, and that for scenario RCP2.6, it gives a likely range of not exceeding 2 °C. He emphasized that WGI did not assess the likelihood of staying below 1.5 °C.

96. One Party asked if in the figure 69 representing the levels of risk for the various **RFC**, the IPCC had **considered adaptation**. An expert explained that the graph does not make specific assumptions on adaptation,

and that the purple colour in the figure is associated with the difficulty of making progress on adaptation. Another expert added that all RFC take into account autonomous adaptation as well as limits to adaptation in the case of RFC1, RFC3 and RFC5, independent of the development pathway, as detailed in the caption to figure 19.4 of the WGII report.

97. **On figure 57** (figure SPM.-10 in the AR5 SYR), one Party asked if **the numbers had been set without considering uncertainties**, such as the likelihood for achieving a temperature limit and the availability of technologies and technology transfer. An expert pointed to references in the AR5 to technology policy and how it complements other policies. The AR5 includes assessments of the costs of various technologies, which could serve as input in considering these technologies and their risks.

98. In response to a question on the **adverse effects of various mitigation technologies**, an expert drew attention to the fact that in the AR5, the IPCC had considered various enabling factors for technology transfer, including institutional arrangements, the provision of finance and the capacity to absorb the technologies adapted to each region.

99. On risk framing and the concept of high adaptation, one Party said that he understood from SED 3 that **high adaptation only has physical and not social or economic constraints**; hence it refers to transformational adaptation, which includes measures such as forced relocation. He added that such a measure is not an option for his country, as it implies fundamental changes in livelihoods and cultural values. An expert clarified that there was no WGII-level guidance that prevented authors from considering relocation as an adaptation option. The definition of a highly adaptive state was left with the writing team to assess, depending on the cultural environment.

100. On the **different costs of achieving the 1.5 °C and 2 °C limits**, one Party noted that the 1.5 °C scenarios require a faster deployment of low-carbon technologies, which imply a higher cost, but that the IPCC had not assessed the costs of these mitigation scenarios. An expert replied that IPCC cost-effective scenarios start with effective mitigation scenarios before 2020. Delayed mitigation action translates to more mitigation costs. He added that the IPCC only reported on the mitigation costs for stabilisation levels analysed in a multi-model, inter-comparison exercise. Since no such multi-model exercises were available for the 1.5°C limit, the mitigation cost was not provided.

101. A representative of civil society asked if it is correct to assume that **if optimal conditions are not achieved in terms of the availability of technologies, zero net emissions would have to be reached earlier than 2050**. She added that CCS is much discussed and not much deployed, prompting questions regarding the implications of its unavailability. An expert pointed to AR5 SYR table SPM.-2, which indicates that mitigation costs increase where CCS is unavailable. He underscored that not all models are successful in carrying out a scenario reaching the 2 °C limit without the wide-scale deployment of CCS. The limited availability of technology leads to the infeasibility of the target or a cost increase.

C. Part 2: The adequacy of the long-term global goal in the light of the ultimate objective of the Convention and overall progress made towards achieving the long-term global goal, including a consideration of the commitments under the Convention based on information from United Nations organizations

1. Presentations by experts

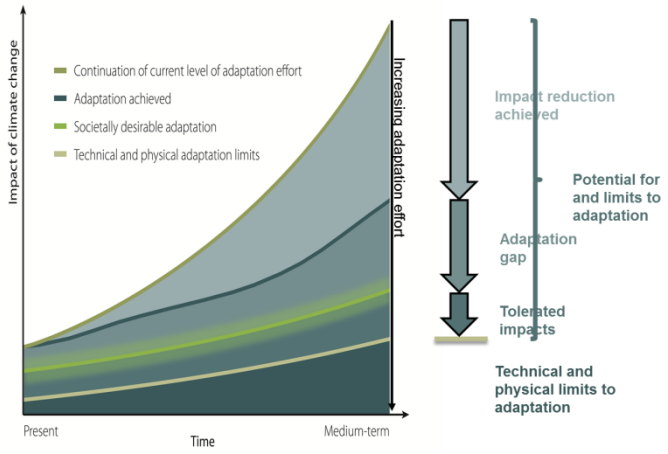
102. Mr. Keith Alverson (UNEP) presented the 2014 Adaptation Gap Report, which proposed a **framework for defining adaptation gaps**, as well as a preliminary assessment of the gap between adaptation needs and reality. He explained that UNEP has been producing the Emissions Gap Report for several years, and that based on the request from Parties, UNEP carried out a preliminary analysis of a similar assessment for adaptation. He noted that **estimating the adaptation gap is far more challenging than calculating the emissions gap** because of the lack of a globally agreed goal or metrics for adaptation, and due to the fact that adaptation is a response to specific climate risks and impacts that are local in nature and vary over time.

103. He described a graph defining adaptation gaps (figure 74), which shows the difference between the present to medium-term impacts of climate change given present adaptation measures (or the business as usual

trajectory) and a trajectory with additional adaptation measures (or a societally desirable adaptation trajectory). He underlined that the gap is therefore the difference between what can be achieved with enhanced adaptation action and what society deems as the goal in terms of adaptation. He added that this societal goal is not zero because **society is ready to tolerate some amount of impact of climate change**, which is determined by local cost-benefit analyses, and some impacts are beyond our technical or physical ability to adapt.

104. On the **financial gap**, he pointed out that a major adaptation funding gap is likely, particularly after 2030, unless new and additional finance for adaptation becomes available. Many global estimates of this funding gap for developing countries exist. According to the World Bank, they range from USD 70 to 100 billion per year globally by 2050.[14] In 2014 Adaptation Gap Report, the authors assessed existing estimates global, sectoral and national estimates, which indicate that the costs of adaptation are likely, at a minimum, to be two to three times higher than World Bank estimates by the 2030s; and could be four to five times higher towards 2050 when results of global, regional, national and sectoral studies are aggregated. He stressed that adaptation costs grow very rapidly over time and are emission dependent. By 2050, adaptation costs could be **around twice as high in a 4 °C warming scenario than in a 2 °C warming scenario**, underlining that the best way to adapt to the impacts of climate change is to mitigate global warming (figure 75).

Figure 74
Defining the adaptation gap



Source: Slide 3 of the presentation by Mr. Keith Alverson (United Nations Environment Programme), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_alverson.pdf>. The figure illustrates, in a schematic form, the concept of the adaptation gap used in the United Nations Environment Programme *Adaptation Gap Report*, which can be defined at the global or local level. The adaptation gap for any point in time is here the remaining difference between already implemented adaptation (dark green line at the bottom of the top grey area) and the potentially achievable adaptation as determined by technical and physical limits (yellow top of bottom dark area). The gap can then further be reduced by the tolerated impacts (difference between light lines in the middle).

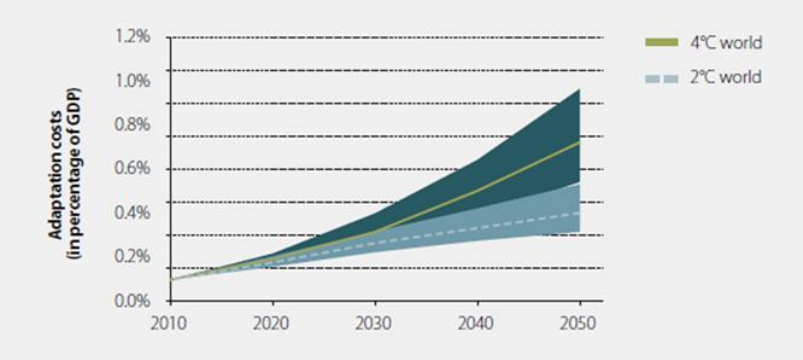
105. Mr. Alverson underscored the difficulty of distinguishing between finance made available for adaptation and that for development or other purposes. Public finance committed to activities with explicit adaptation objectives ranged between USD 23 and USD 26 billion in 2012–2013, of which 90 per cent was invested in developing countries. He indicated that adaptation finance flows have increased in recent years across all sources of finance and are increasingly mainstreamed in development cooperation. He pointed out that only about two per cent of total adaptation finance came from multilateral mechanisms (USD 0.6 billion committed to developing countries in 2013), but noted an increasing trend.

106. While stressing the **need to urgently scale up climate adaptation finance flows**, he underlined that: the Green Climate Fund (GCF) can play a central role in bridging the adaptation funding gap and its capitalization is close to reaching USD 10 billion; adaptation costs and finance needs are emission dependent and will rise more quickly under higher emission scenarios; risks and needs are not equally distributed, and least developed

[14] The World Bank. 2010. Economics of Adaptation to Climate Change - Synthesis Report. Available at <http://documents.worldbank.org/curated/en/2010/01/16436675/economics-adaptation-climate-change-synthesis-report>.

countries (LDCs) and small island developing States (SIDS) are likely to have much higher adaptation needs; and current analyses underestimate finance flows, as they do not include private sector and domestic spending.

Figure 75
Adaptation costs are emissions dependent



Source: Slide 5 of the presentation by Mr. Keith Alverson (United Nations Environment Programme), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_alverson.pdf>. The figure shows that by 2050, adaptation costs could be around twice as high in a 4 °C world scenario (solid green line and dark green area) than they are in a 2 °C scenario (dashed line, grey area). The areas show the likely (66 per cent) range of costs.
Abbreviation: GDP = Gross Domestic Product

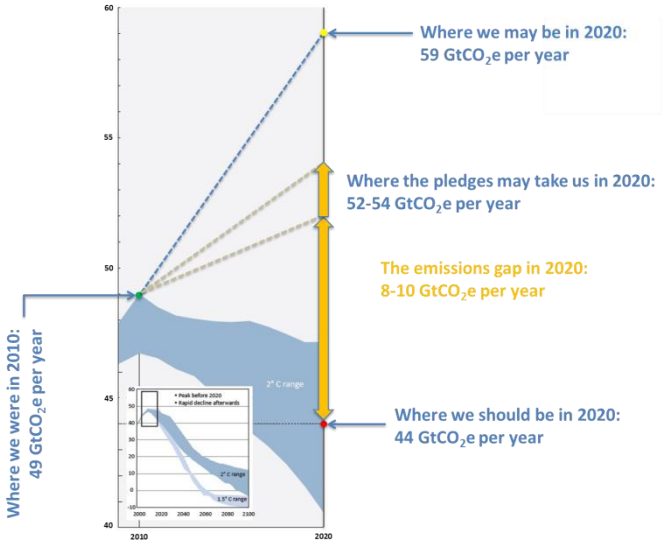
107. On the **technology gap**, estimates are largely drawn from the technology needs assessments communicated by Parties, as well as the technology made available through mechanisms such as the Climate Technology Centre and Network (CTCN) of the UNFCCC and others. Mr. Alverson underlined that the most appealing technology solutions are those that serve a variety of purposes above and beyond climate adaptation. There is a trade-off between the need to measure adaptation and the use of these integrated measures, which are more difficult to quantify than those solely targeting climate adaptation. He also underscored the importance of the acceleration of the diffusion of existing technologies and the role of research and development in adjusting existing technologies to local conditions. He identified scope for addressing gaps in knowledge production, knowledge integration, and knowledge transfer and uptake through a more efficient use of existing knowledge, systematic approaches and analysis, and improved monitoring and evaluation. To sum up, **there is significant potential to reduce the overall adaptation gap in the short and medium term through knowledge and technology**.

108. On the **knowledge gap**, he stated that a large portion of this gap is likely to be related to the transfer of knowledge. He referred to an article published in November 2014 in *Science*, which argues that **universal education is the key to adaptation**. The article points out that countries with the highest level of education are those that are best adapted to extreme climate events. In the *Adaptation Gap Report*, the authors have attempted to define a knowledge goal, particularly in assessing the effectiveness of adaptation action. He described the Adaptation Knowledge Initiative, carried out by UNEP, the UNFCCC Nairobi Work Programme and other partners, which aims to quantify and rank knowledge gaps regionally and by sector in an attempt to close the knowledge gap.

109. Mr. John Christensen (UNEP) presented on *The Emissions Gap Report 2014*. He explained that the origins of the report go back to COP 15 at which 141 Parties signed the Copenhagen Accord. Among the provisions of the Accord was a call to Parties to submit voluntary emission reduction pledges for 2020 and the setting of a temperature target. These two provisions raised the following question: **will pledges for 2020 be enough to meet the temperature target?**

110. UNEP published the first *Emissions Gap Report* ahead of COP 16 in late 2010. Many Parties to the Convention found this first edition useful and asked UNEP to update it annually, to inform negotiations on the level of ambition required from countries to meet the temperature target. The editions of the report provide an indication of: **what has been done in all these years**; **where emission trends seems to be taking us**; **where the full implementation of the pledges made after Copenhagen would take us**; and **where science modelling tells us we should be to reach the 2 °C limit**. He said the emissions gap is close to what was assessed in 2013, and that the gap has been almost constant for the past five years.

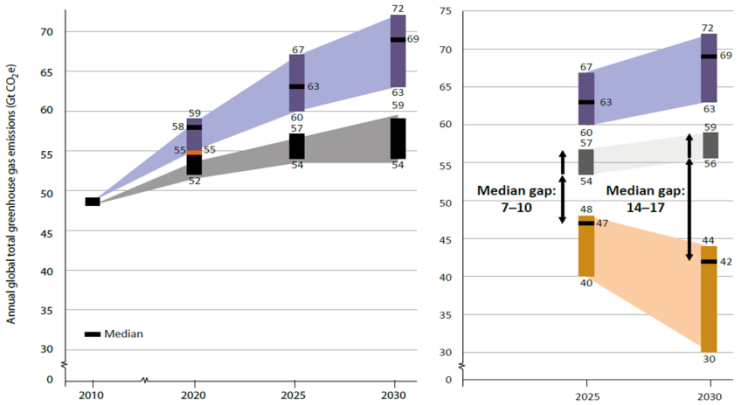
Figure 76
The emissions gap in 2020



Source: Slide 2 of the presentation by Mr. John Christensen (United Nations Environment Programme), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_christensen.pdf>. The figure shows that the emissions gap in 2020 remains at 8–10 Gt CO_2 eq per year as the difference between the Cancun pledges and emission pathways compatible with limiting warming below 2 °C above pre-industrial levels.
Abbreviation: $GtCO_2eq$ = Billion tonnes of CO_2 equivalent.

111. He explained that the top line indicates the 'business as usual' scenario at 59 Gt CO_2 eq, and the third line down illustrates emissions levels with the most stringent implementation of pledges, these are then compared to the median level of 44 Gt CO_2 eq for scenarios that meet the 2 degree target, which leaves a 8–10 Gt CO_2 eq gap in the year 2020 (figure 76). For this edition of the *Emissions Gap Report*, UNEP moved to a new set of models beyond 2020, looking at 2030 to inform the decision-making process. This is because the old models had a starting point for cost-efficient implementation in 2010, which did not happen. The new models therefore have a starting point of cost-efficient implementation in 2010, when the new climate agreement should apply. These new models imply steeper reductions of GHGs after 2020, higher mitigation costs, negative emissions and significantly higher climate risks.

Figure 77
The emissions gap in 2025 and 2030

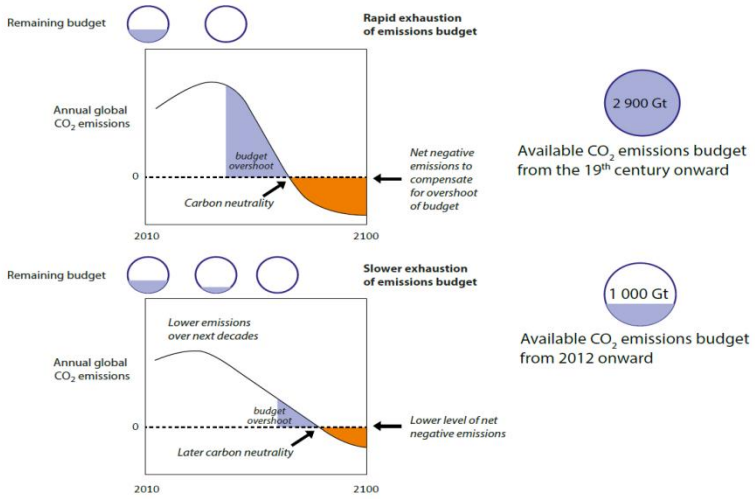


Source: Slide 4 of the presentation by Mr. John Christensen (United Nations Environment Programme), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_christensen.pdf >. The figure shows that the emissions gap in 2025 is 7–10 Gt CO_2 eq, and in 2030, the gap is significantly bigger, at 14–17 Gt CO_2 eq.
Abbreviation = $GtCO_2eq$: Billion tonnes of CO_2 equivalent.

112. Mr. Christensen indicated that since climate change negotiations are increasingly focusing on 2030, the 2014 edition of the *Emissions Gap Report* provides estimates of the gap in 2025 and 2030 (figure 77). To do so, UNEP calculated emission growth rates in the period 2020–2030 in four sectors: energy; non-CO_2 GHG emissions; CO_2 emissions from industry; and emissions from land-use change. He added that for the energy sector, UNEP used IEA data, and for the other three sectors UNEP used data from the IPCC scenario database. By combining these growth rates with the share of global emissions of each of the sectors above, UNEP extrapolated to 2030 the low- and high-end of the four pledge cases in 2020. By interpolation, UNEP obtained an estimate for 2025. **The emissions gap in 2025 is 7–10 Gt CO_2 eq, and in 2030 the gap is significantly bigger, at 14–17 Gt CO_2 eq.**

113. He pointed to the focus in this year's edition on targets for 2030, and the emission budget for staying within the 2 °C limit, and referred to the discussions held during part 1 of SED 4-1 on the carbon budget, which corresponds to the total amount of carbon emissions that can be emitted while still staying within that limit.

Figure 78
The remaining carbon budget



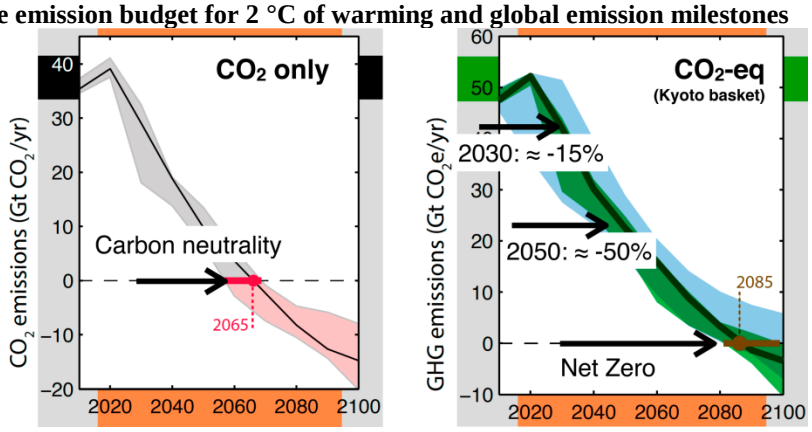
Source: Slide 5 of the presentation by Mr. John Christensen (United Nations Environmental Programme), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_christensen.pdf >. The figure illustrates the differences between early (bottom) and delayed action (top) in terms of the pathway of global emissions for remaining under 2 °C of warming relative to pre-industrial levels.

Abbreviation: Gt = a billion tonnes

114. He explained that at present, we have about 1,000 $GtCO_2eq$ available in our budget, down from 2,900 at the beginning of the industrial revolution (figure 78). If we focus on **CO_2 only, emissions need to decrease to net zero between 2055 and 2070 to stay within the 2 °C limit** (figure 79). Meanwhile, all GHGs emissions need to decrease to net zero between 2080 and 2100 to stay within the 2 °C limit. He stressed that the longer we wait on getting the curve bent, the steeper the curve, even with negative emissions towards the end of the century. He added that carbon neutrality and, in many cases, negative emissions will have to be reached, implying that carbon will have to be totally taken out of the system, through large deployment of biomass energy with CCS, or massive scale tree planting, stressing that the ensuing land, water and population requirements will be very challenging.

Figure 79

How to spend the emission budget for 2 °C of warming and global emission milestones



Source: Slide 5 of the presentation by Mr. John Christensen (United Nations Environment Programme), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_christensen.pdf>. The figure identifies the period 2055–2070 as the net zero CO_2 emissions window, and 2080–2100 as the net zero emissions window for total greenhouse gas emissions for emission pathways compatible with limiting warming below 2 °C above pre-industrial levels.

Abbreviation: Gt CO_2 eq = Billion tonnes of CO_2 equivalent emissions.

115. In concluding, Mr. Christensen underlined that a qualitative assessment of the mitigation potential of various key sectors and of country pledges shows that, on average, about 10–30 per cent of the mitigation potential identified is contained in the actual pledges, pointing to the large room for increasing ambition. On energy efficiency, he underscored that it involves various actors and a wide range of wins, and "hardly any loses".

116. Mr. Stéphane Hallegatte (World Bank) gave a presentation on low-carbon resilient development, with a focus on pricing carbon. He underscored that the World Bank sees climate change as a development challenge that no 'silver bullet' can fix, stressing the need for policy packages. On mitigation, he noted the robust scientific findings in the AR5 on the relationship between cumulative CO_2 emissions and temperature. To stabilize climate change, **net CO_2 emissions need to be reduced to zero**. The question is therefore the speed at which this goal is achieved, since it will determine the temperature change.

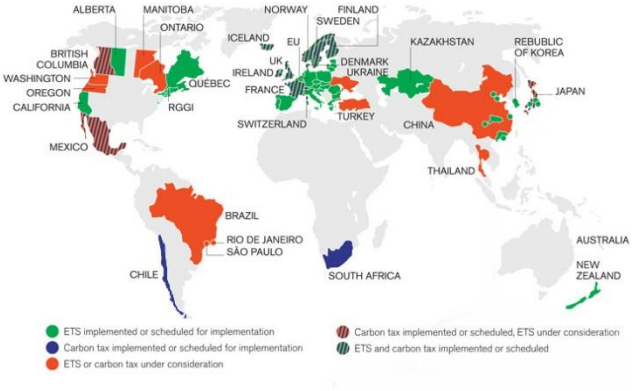
117. He identified four elements common to all models that provide the emission reductions required to bring emissions to zero at the end of the century, regardless of the temperature target, namely the need to: **improve energy efficiency**, with better buildings, cars, light, appliance, etc.; **carry out a fuel shift in most economic activities**, including transport, heating and industries; **decarbonize electricity generation**; and **implement land-use changes** in forestry, agriculture and urban development. He stressed that these four elements require immediate actions in different sectors.

118. Noting that "we know what needs to be done", he described the support provided by the World Bank for countries to: reform fossil fuel subsidies and carbon pricing; improve energy efficiency; enhance renewable energy uptake and diversify their economy; double the rate of improvement of energy intensity by 2030, as called for by the SE4ALL initiative; carry out land-use planning, city planning and financing; and finance public transit.

119. **On fossil fuel subsidies and carbon pricing**, he referred to the United Nations Climate Summit held in September 2014, where 73 countries and over 1,000 investors and firms **called for carbon pricing** as a tool to ensure that climate change is mitigated in an efficient manner, underlining the importance of complementary social measures to ensure that the reform is not damaging poverty reduction. He also pointed to the Bank's goal of stopping illegal deforestation by 2030 and making 100 per cent of the World Bank Group's agriculture projects climate-smart by 2018. **On carbon pricing**, Mr. Hallegatte mentioned the *State and Trends of Carbon Pricing 2014*, which indicates that it is gaining momentum, highlighting its **large co-benefits in terms of**

development and well-being[15] (see figure 80). He also referred to *Climate-smart Development*, which looks at the co-benefits that climate policy can bring, emphasizing that reduced air pollution and health-related deaths are some of the largest co-benefits of climate change mitigation.[16]

Figure 80
Carbon pricing is gaining momentum



Source: Slide 9 of the presentation by Mr. Stéphane Hallegatte (World Bank), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_hallegatte.pdf>. The figure shows the world map highlighting countries where various schemes for carbon pricing have been implemented or are scheduled.
Abbreviation: ETS = emissions trading scheme.

120. **On adaptation and resilience**, he cautioned that even if the target is 1.5 °C or 2 °C, it would be too risky to assume that it will be reached when planning for adaptation, pointing to the critical example of climate sensitivity uncertainty. The World Bank therefore plans adaptation with more pessimistic scenarios. Mr. Hallegatte explained that the series of three reports titled *Turn Down the Heat* investigates how impacts vary when warming increases from 2 °C to 4 °C above pre-industrial levels, and finds that "the difference is huge" (figure 81).[17] For example, in a world **2 °C warmer, water availability is projected to be reduced by 20 per cent, while this would go up to 50 per cent in a world 4 °C warmer**. The same **non-linearity exists for projected heat extremes, or the bleaching of coral reefs, with close to double impacts in a world 4 °C warmer compared with 2 °C warmer than in pre-industrial times, implying very different adaptation needs**. In the light of uncertainty about temperature change in the future, adaptation planning needs to take into account the possibility of global warming of 4 °C or higher.

121. **On climate change and poverty**, he stressed that the poor are often more exposed and more vulnerable to extreme weather events. He pointed to the example of the city of Mumbai in India, where the lowest quintile is disproportionally represented in the flood zone, and the richest quintile is almost absent. He added that when households are affected, as was the case in 2005, they can lose all their savings and approximately a year of income, representing significant obstacles to saving and accumulating the assets needed to escape poverty.

122. He stressed the dynamics of poverty, using the example of Andhra Pradesh in India, where the flows out of poverty are 14 per cent per year, but where 12 per cent of households fall back into poverty every year. The flows out of poverty are therefore small compared with annual flows in and out of poverty. He warned that: relatively minor impacts on these flows in and out of poverty can have a large impact on net poverty reduction; weather events are already a major cause for people to fall into poverty and constitute major obstacles for people

[15] World Bank Group. 2014. State and Trends of Carbon Pricing 2014, May 2014. Available at <http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2014/05/27/000456286_20140527095323/Rendered/PDF/882840AR0Carbo040Box385232B00OUO090.pdf>.

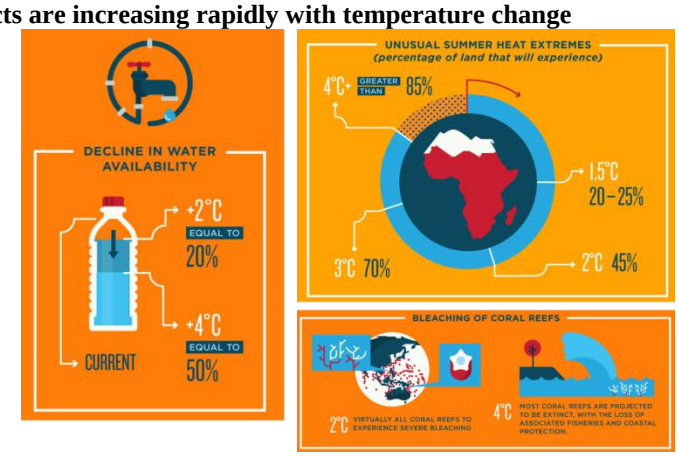
[16] Climate Works Foundation and World Bank Group. 2014. Climate-smart Development. Available at <https://openknowledge.worldbank.org/bitstream/handle/10986/18815/889080WP0v10RE0Smart0Development0Ma.pdf?sequence=1>.

[17] World Bank. Turn Down the Heat. Available at <http://www.worldbank.org/en/topic/climatechange/publication/turn-down-the-heat>.

to escape poverty; and in the absence of strong action, climate change will magnify these effects, potentially creating a significant drag on poverty reduction and a threat to sustained poverty eradication.

Figure 81

Climate change impacts are increasing rapidly with temperature change



Source: Slide 13 of the presentation by Mr. Stéphane Hallegatte (World Bank), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_hallegatte.pdf>. The figure indicates the non-linear relationship between temperature increase and adaptation needs, and that adaptation needs for a 4 °C warmer world scenario and a 2 °C scenario are very different.

123. On the International Development Association (IDA), the World Bank's fund for low-income countries, he highlighted commitments to better mainstream climate and resilience into development, and to screen all IDA projects for climate and disaster risks, pointing to ongoing work on developing and improving tools to do so.

124. In concluding, he underscored the importance of considering climate policies, related to both adaptation and mitigation, as development issues.

125. Ms. Christina Hood (IEA) gave a presentation on the challenges and opportunities related to energy and climate change, describing: the current state of the energy sector; modelling results and five key actions to achieve a low-carbon energy sector; and issues related to technology risk and risk management.

126. To describe the current state of the energy sector, she listed relevant IEA resources: energy and CO_2 statistics;[18] free online database; smartphone apps; energy efficiency indicators; the *Energy Efficiency Indicators: Fundamentals on Statistics*[19]; energy technology, and research and development indicators; medium-term market reports; the *World Energy Outlook*[20] and *Energy Technology Perspectives*[21] scenario analysis; and policy studies.

127. Besides emission levels, she said that another key aspect of the transition towards a low-carbon economy is the development of the needed technologies. In the *Tracking Clean Energy Progress Report 2014*,[22] the IEA compares how quickly key clean energy technologies are being developed and deployed compared to interim 2025 targets in the *IEA 2014 Energy Technology Perspectives* 2 °C scenario, which lays out pathways to a sustainable energy system in 2050.

[18] See IEA statistics web page, available at <http://www.iea.org/statistics/>; and CO2 statistics. Available at <http://www.iea.org/statistics/topics/co2emissions/>.

[19] IEA. 2014. Energy Efficiency Indicators: Fundamentals on Statistics. Available at <http://www.iea.org/publications/freepublications/publication/energy-efficiency-indicators-fundamentals-on-statistics---.html>.

[20] IEA. 2014. World Energy Outlook 2014. Available at <http://www.worldenergyoutlook.org/publications/weo-2014/>.

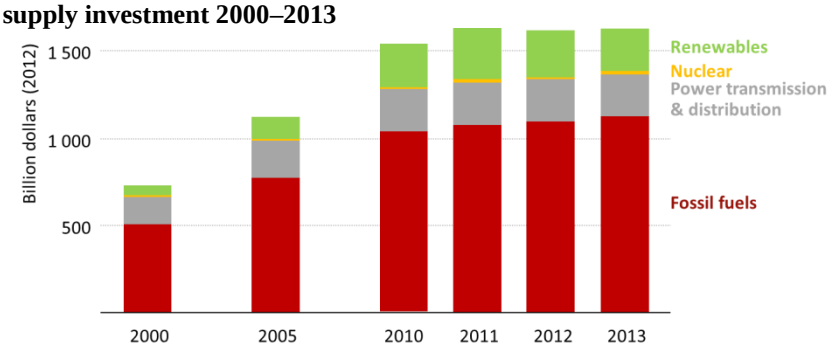
[21] IEA. 2014. Energy Technology Perspectives 2014. Available at <http://www.iea.org/bookshop/472-Energy_Technology_Perspectives_2014>.

[22] IEA. 2014. Tracking Clean Energy Progress Report 2014. Available at <http://www.iea.org/publications/freepublications/publication/Tracking_clean_energy_progress_2014.pdf>.

128. Ms. Hood underlined that this assessment indicates that technology development is off track for levels consistent with a 2 °C scenario, except for renewable power generation. She explained that **"we are not on track" not only in relation to turning the tide of coal, but across the entire energy system**. She warned against the costs of delaying action to transform our energy system. The **only exception – renewables - is not enough to meet long-term sustainable energy goals**. She stressed that a broad range of technologies are needed across all production, generation and end-use sectors – especially in the electricity sector. Ms. Hood cautioned that without progress in the development, demonstration and deployment of these technologies, it will not be possible to meet long-term climate, security and economic goals for energy systems, calling on policy-makers to "change this picture".

129. On investments, Ms. Hood underscored that investment in energy supply has doubled since 2000 and investment in renewables has scaled up considerably, but fossil fuels still dominate energy supply investments (figure 82).

Figure 82
Annual energy supply investment 2000–2013



Source: Slide 6 of the presentation by Ms. Christina Hood (International Energy Agency), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_hood.pdf >. The figure shows that fossil fuels still dominate annual energy supply investments.

130. On the ownership of worldwide power generation capacity and oil and gas reserves, she noted that a large proportion is held by state-owned companies. As a result, alongside investment by the private sector, the objectives, corporate culture and financing of state-owned companies will be critical to future energy investment flows.

131. On the key results of the IEA long-term models, she explained that from the *World Energy Outlook* and *Technology Perspectives*, the IEA extracted **six key measures** to achieve the 2 °C pathway (see figure 28).

132. **First**, action should start immediately, both to keep the emission pathway within reach and to limit the emission overshoot, but also to **implement some cost-effective short-term action** that can stop the growth in emissions by 2020 at no net economic cost, reducing emissions by 3.1 Gt, and carrying out 80 per cent of the savings required for a 2 °C pathway (figure 83). These measures include: implementing selected energy efficiency policies; limiting the use of inefficient coal power plants; reducing CH_4 releases from upstream oil and gas; and partially removing fossil-fuel subsidies.[23] She stressed that these measures are GDP-neutral in every region in the IEA model. She explained that renewable energy is not mentioned in the figure because it is already in the baseline scenario of the model.

133. **Second**, the **electricity sector should be decarbonized**. She compared a 6 °C scenario – if current policies remain in place – to the 2 °C scenario, where a dramatic change in the power sector takes place, with 94 per cent of electricity generated from low-carbon sources (renewables, nuclear, CCS) in 2050, and which will require focused attention from policy-makers.

[23] IEA. 2013. World Energy Outlook Special Report: Redrawing the Energy-Climate Map. Available at <http://www.iea.org/publications/freepublications/publication/weo-special-report-2013-redrawing-the-energy-climate-map.html>.

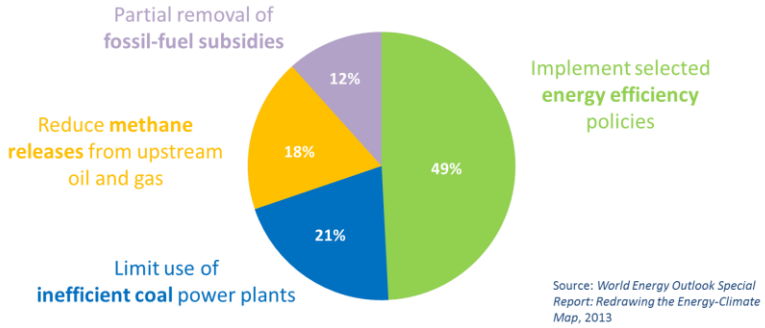
134. **Third, investment patterns need to be reshaped**, especially for long-lived infrastructure. She compared the 450 ppm scenario to a new policies scenario, where efficiency spending is USD 6 trillion higher and the composition of supply investment changes, with the wide deployment of CCS and USD 300 billion of fossil fuel investment left stranded. In both scenarios, the total quantity of investment does not change much in energy supply, but there is a large shift from fossil fuels to low-carbon technologies. In addition, there is a scaling-up in investments of a factor of about four compared with current levels in energy efficiency and clean energy supply.

135. **Fourth, innovation in key technologies needs to be accelerated**, both in the short and in the long-term. In the short-term, renewables and energy efficiency are key in delivering emission savings. In the longer term, investments should be made now to ensure that technologies related to CCS and end-use fuel switching, including the electrification of transport, will be available when they are needed.

136. **Fifth, non-climate drivers of actions that reduce emissions should be harnessed**. She stated that in many cases, these non-climate drivers are the real reasons why governments take action. She called on the UNFCCC process to harness these other objectives, such as economic development, air quality improvement, energy security or road congestion alleviation, in order to maximize action on the ground.

137. **Sixth, the energy sector needs to become more resilient** to both extreme events and long-term gradual changes.

Figure 83
Cost-effective short-term action to achieve the 2 °C pathway



Source: Slide 9 of the presentation by Ms. Christina Hood (International Energy Agency), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_hood.pdf>. The figure shows that four measures can stop the growth in emissions by 2020 at no net economic cost.

138. Ms. Hood then addressed **managing technology risks**, underlining that technology delay will increase the costs and reduce the feasibility of low-carbon scenarios. To ensure that technologies needed for the transition to a low-carbon economy are available and at scale, she stressed the need for: international collaboration to share best-practice policy frameworks for research, development and demonstration (RD&D) support and evaluation; a portfolio approach to RD&D; the tracking and reporting of the global level of investment in technology development; a strong focus on energy efficiency; and economy-wide broad-based policies for implementation.

139. In concluding, she noted that **current policies and investment patterns are not consistent with a 2 °C scenario,** but that **moving to a 2 °C pathway is technically possible and affordable, but requires sustained efforts**. To achieve this pathway, she outlined key actions, namely: act to reduce emissions pre-2020; focus on the decarbonization of the power sector; shift investment patterns; accelerate clean energy technology development; harness non-climate objectives; build resilience; and mitigate the risks of technology delay.

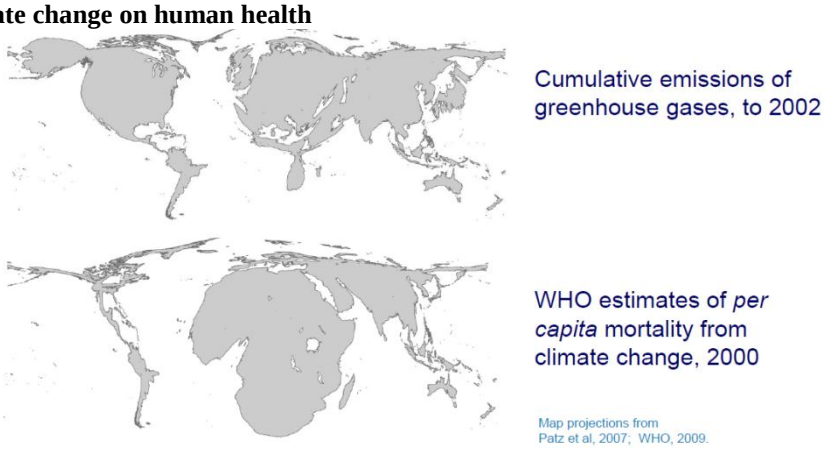
140. Ms. Kristie Ebi (WHO) gave a presentation on the health impacts of climate change. She stated that for the health community, there is no 'safe limit' for climate change and current climate risks are already unacceptable, underlining the importance of urgent adaptation and mitigation action. For WHO, the definition of 'tolerated impacts' is different to that used in the UNEP *Adaptation Gap Report*. There is a wide range of health outcomes that cause significant morbidity and mortality around the world today, many of which are sensitive to weather and climate. A small proportion of deaths from climate-sensitive health outcomes are currently due to climate change, indicating that **people are already suffering and dying from climate change**, which, from the perspective of the health sector, is intolerable.

141. She presented two world maps representing the cumulative emissions of GHGs to 2002, and the WHO estimates of per capita mortality from climate change in 2000, highlighting the extremely uneven distribution of emissions and impacts (figure 84).

142. Ms. Ebi pointed to the example of the heat wave in the Russian Federation in 2010, which lead to fires, heavy air pollution and about 11,000 excess deaths. It is estimated, with an 80 per cent level of confidence that the 2010 Moscow heat wave (and associated deaths) was due to climate change.

143. She then presented a graph from the human health chapter of the WGII contribution to the AR5, which illustrates the health impacts of climate change and the potential for adaptation (figure 85). The graph also shows the challenges that will have to be faced and what the residual risks could be. For each section of the pie, the orange indicates the risk levels with current levels of adaptation, while the yellow sections indicate the risks after high levels of adaptation. She underlined that this figure is based on the literature assessed in the AR5 and on expert judgment. Unfortunately, the efforts required to achieve high levels of adaptation are not consistent with current levels of funding for adaptation or technology transfer. In comparison with the current levels of risk, 1.5 °C of warming is projected to lead to very large increases in health risks, both in what can be avoided and what will remain. In a world 4 °C warmer, the risks are very high.

Figure 84
Impacts of climate change on human health



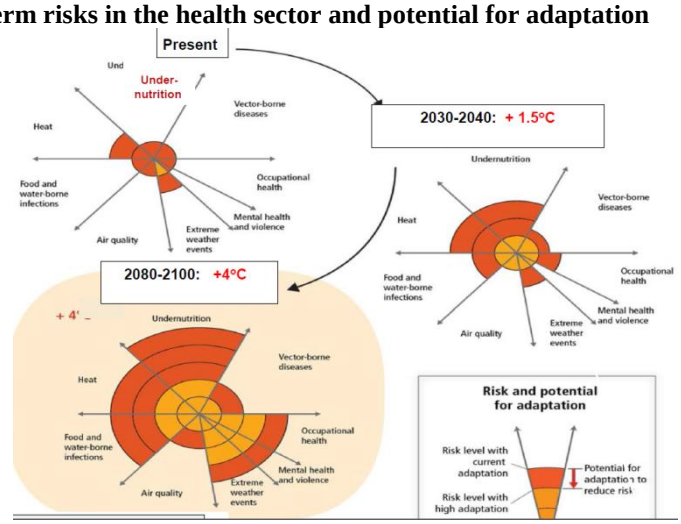
Source: Slide 3 of the presentation by Ms. Kristie Ebi (World Health Organization), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_ebi.pdf>. The figure shows the origin of cumulative emissions per continent and/or region by altering the relative size of the area (upper map, shrunken area means below average, enlarged area above average emissions) and similarly the estimates of per capita mortality (bottom map).

144. As another example, she referred to the ability of people to work in very high temperatures. She explained that full working capacity declines as temperature increases. According to the AR5, in Southeast Asia, in 2050, more than half of the afternoon work hours may be lost due to the need for rest breaks. According to a paper by Sherwood and Huber in the *Proceedings of the National Academy of Sciences*, a 10 °C of warming, large populated areas of the global would be in many respects uninhabitable.[24]

145. Ms. Ebi then presented WHO estimates from fall 2014 of **mortality due to climate change: approximately 150,000 excess deaths per year at present, and approximately 250,000 in 2030**. She noted that these are only estimates of the four health outcomes for which there was sufficient information to run a model, not all possible health outcomes (figure 86).

[24] Proceedings of the National Academy of Sciences. 2010. Available at <http://www.pnas.org/content/by/year/2010>.

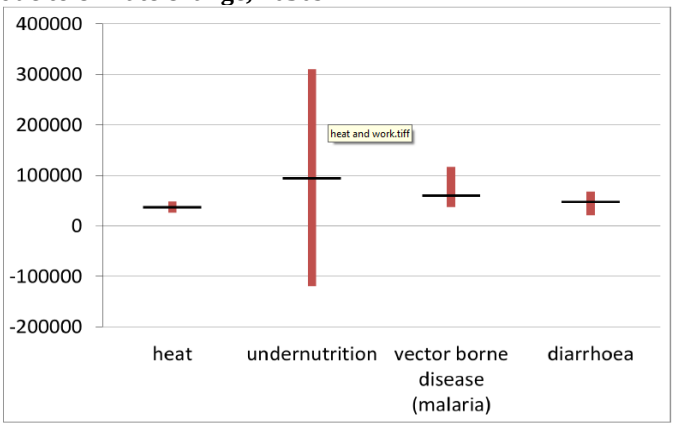
Figure 85
Near-term and long-term risks in the health sector and potential for adaptation



Source: Slide 5 of the presentation by Ms. Kristie Ebi (World Health Organization), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_ebi.pdf>. The figure shows various health risks for humans as posed by climate change at present, at 1.5 °C and at 4 °C of warming above pre-industrial levels, as well as the potential for adaptation (dark orange areas; light orange areas represent the remaining risks under high adaptation).

146. She listed other WHO reports that aim to help countries facing the risks of climate change to improve the resilience of the health sector: the *Atlas of Health and Climate*;[25] *Protecting Health from Climate Change – Vulnerability and Adaptation Assessment*;[26] and *WHO Guidance to Protect Health from Climate Change through Health Adaptation Planning*.[27] She stressed the importance of mainstreaming health concerns in other sectors, noting that choices made in other sectors should be health-resilient.

Figure 86
Estimates of mortality due to climate change, 2030s



Source: Slide 7 of the presentation by Ms. Kristie Ebi (World Health Organization), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_ebi.pdf>. The figure shows the estimates of excess mortality due to heat, under-nutrition, vector-borne disease, and diarrhoea, caused by climate change in the 2030s assuming the SRES A1B scenario and 50 per cent adaptation.

[25] World Health Organization. 2012. Atlas of Health and Climate. Available at <http://www.who.int/globalchange/publications/atlas/en/>.

[26] World Health Organization. 2011. Protecting Health from Climate Change – Vulnerability and Adaptation Assessment. Available at <http://www.who.int/globalchange/publications/Final_Climate_Change.pdf>.

[27] World Health Organization. 2013. WHO Guidance to Protect Health from Climate Change through Health Adaptation Planning. Available at <http://apps.who.int/iris/bitstream/10665/137383/1/9789241508001_eng.pdf?ua=1>.

147. In concluding, she underlined that: there is no 'safe limit' for health, as climate variability and change are already impacting health significantly and inequitably; higher rates of warming are projected to further increase health risks; various thresholds exist at individual and community levels but are not linked to specific rates of global warming; much, but not all, of the current and future burden could be avoided through proactive and efficient adaptation; and mitigation is critical to reduce future health threats, as a precaution against uncertain risks and to gain large health co-benefits.

148. Mr. Alexandre Meybeck (FAO) gave a presentation on agriculture, food security and climate change. He described the triple challenge of: producing more food, in quantity, quality and diversity, everywhere for everyone; adapting to climate change; and contributing to climate change mitigation. He underscored that the **world's population will increase by one third by 2050, thereby increasing food demands**, and stressed that in some areas, population will double or triple, and that often these are areas that are the most food insecure and vulnerable to climate change. Mr. Meybeck indicated that FAO estimates that **global agricultural production will have to increase by 60 per cent by 2050** to satisfy the increase in demand driven by population growth and diet changes.

149. With regards to adaptation, he stressed that there are **huge gaps in knowledge about the impacts of climate change on a lot of crops and on agro ecosystems**, such as pollinators. These gaps in knowledge exist for all the interrelations in the soil or on the farm that enable farmers to produce food. **There is no safe limit to the increase in emissions because of the uncertainties about the impact of climate change on these complex ecosystems**. Another area where there are significant gaps in knowledge is crop and animal diseases, which are impacted by climate change. In short, we do not have enough information about the impacts of climate change on biophysical ecosystems. This information gap is even more significant in relation to food systems, which combine biophysical and socioeconomic systems.

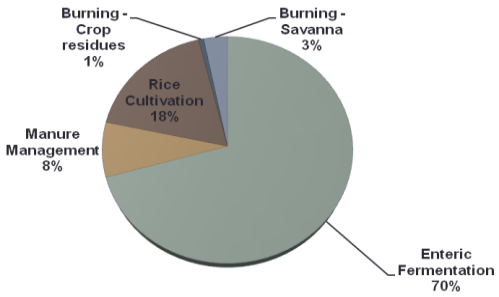
150. What is certain is that with climate change, there will be a decrease of production in certain areas, changes in the geography of production, and an increased variability of production. All of these will have an impact on all the dimensions of food security and nutrition, with stronger impacts on the most vulnerable countries and the most vulnerable people, including small holders. There is less knowledge on the impacts of nutrition, because most of the research has been carried out on staple crops.

151. With regards to mitigation, agriculture can **reduce emissions per kilogram of output** – or decouple production and emission growth, and enhance agricultural soil carbons sinks.

152. He explained that FAO combines the three objectives of producing more food, adapting to climate change and contributing to climate change mitigation, through **climate-smart agriculture** (CSA), which focuses on more resource-efficient and resilient ecosystems. Resilience needs to be viewed at different scales from both a socioeconomic and an environmental and ecosystem perspective.

153. He said a large part of the mitigation potential of agriculture is in land use, which implies decreasing deforestation, sustainably increasing the production on degraded lands and decreasing emissions from livestock. On livestock, he underlined that **agriculture accounts for 50 per cent of global CH_4 emissions, and within agriculture 78 per cent of CH_4 emissions are from livestock** (figure 87).

Figure 87
Methane emissions from livestock



Source: Slide 16 of the presentation by Mr. Alexandre Meybeck (Food and Agriculture Organization of the United Nations), available at <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/141203_sed4_meybeck.pdf>. The figure shows that 78 per cent of methane emissions are from livestock.

154. **CH_4 emissions are also energy losses**, so reducing methane emissions results from improved natural resources use efficiency. He stated that a wide range of technical interventions can improve natural resource use efficiency and productivity while reducing emissions, including: using grazing in place of feed, improvements in the management of the herd, better genetics, better feeding programmes and better veterinary services. There are **non-climate drivers** of action and these are those we need to mobilize if we want to incentivize farmers to take action.

155. This focus on livestock shows opportunities for high impact: livestock represents 78 per cent of agricultural and 40 per cent of global CH_4 emissions; livestock production is expected to grow; the reduction in emissions from livestock comes at low cost and with a wide range of co-benefits (climate, productivity, profitability, food security, nutrition, human health, green energy, etc.); and technologies are available and provide cost-effective reduction opportunities, especially for low productive systems, using relatively common practices, although a number of barriers need to be overcome.

156. He used the example of a project in Zambia to illustrate that the margin for reducing emissions in the agricultural sector without threatening food production and food security is limited. In concluding, he emphasized that the key is to increase natural resource efficiency while being able to resist the impact of climate change. Globally, the more efficient a breed, the more sensitive it is to any variations, especially to heat waves.

2. General discussions

157. The ensuing discussion was guided by the following questions:

(a) We heard from the IPCC that increasing magnitudes of warming will increase severe, widespread and irreversible impacts of climate change. In the light of this, what are the risks assessed by your organization on human health, food production and other ecosystem services at a 1.5–2.0 °C level of global mean warming compared with pre-industrial levels, and how does your organization contribute to reducing and managing these risks?

(b) What is the gap between current mitigation and adaptation efforts and those required to achieve the long-term global goal as characterized by a 1.5–2.0 °C level of warming relative to pre-industrial levels? How can this gap be bridged?

(c) What policy options has your organization identified for the decarbonization of the energy system called for by pathways consistent with limiting warming below 1.5 °C or 2 °C compared with pre-industrial levels? What are the economic and technological risks associated with this decarbonization?

(d) How effective have the steps taken by your organization been in terms of supporting national activities aimed at minimizing the impacts of climate change? What barriers have your organization encountered and how has it succeeded in overcoming them?

(e) Which policies and measures has your organization identified as effective to bridge the emissions and adaptation gap, and how can these policies and measures be emulated?

158. Noting that the *Adaptation Gap Report* presented the adaptation costs for scenario RCP2.6, which projects the lowest median global warming of all the RCP scenarios (approximately 1.6 °C by 2100), one Party asked about the **adaptation cost implications of an additional 0.5 °C of warming**. She also asked for more information on the estimate that adaptation costs would be 3–4 or 4–5 higher than previous World Bank estimates, and on the **distribution of these costs**, especially in relation to SIDS and LDCs. An expert explained that UNEP used scenario RCP2.6 for the 2 °C limit, so actually the lower cost estimate corresponds to 1.5 °C than 2 °C of warming, but the cost ranges for the two temperature limits overlap significantly in the early decades.

159. On the **differences in the cost estimates**, one expert explained that this stems from the fact that the *Adaptation Gap Report* not only examined global studies, but also sectoral and national studies, and that the latter contain huge variations in the climate scenarios applied, the methods used and assumptions made, and the temporal, spatial and sectoral scope of coverage. In addition, national studies have more realistic assumptions on barriers to implementation of adaptation, which tend to raise the costs significantly. Another expert added that higher estimates of adaptation costs are due to the fact that the coverage of previous estimates was limited in terms of sectors, whereas in the *Adaptation Gap Report*, the authors assessed more sectors and more countries;

the World Bank estimates were based on a 2 °C pathway, whereas a 4 °C pathway raises significantly the costs of adaptation, and the national-level studies examined do not always distinguish between the 2 °C and 4 °C scenarios; and in previous assessments, the gains and losses from adaptation were aggregated, potentially lowering the costs of adaptation, but in the *Adaptation Gap Report* this was corrected to be more precise, as often gains and costs are often not comparable between sectors. Yet another expert underscored that some of the vulnerability is linked to the lack of infrastructure, and that the World Bank estimates that infrastructure lacks USD 1–1.5 trillion per year.

160. On the **regional distribution of adaptation costs**, an expert emphasized that when there is an existing development and adaptation deficit, future adaptation costs are projected to be much higher, as is the case in SIDS and LDCs, although no specific estimates for SIDS or LDCs are currently available.

161. One Party asked for confirmation that the *Emissions Gap Report* assesses relevant literature on scenarios that return warming to below 1.5 °C above pre-industrial levels by 2100, and that there are technologically and economically feasible scenarios available in the literature that achieve this limit. She asked if **the same methodology as was used in the scenario analysis of the *Emissions Gap Report* to provide emission benchmarks for 2025 and 2030 could be applied to these 1.5 °C scenarios**. An expert clarified that for the *Emissions Gap Report*, UNEP focused on 2 °C of warming as the main area for analysis, but that there has also been work on the 1.5 °C scenario. Another expert confirmed that, for the 2014 edition of the *Emissions Gap Report*, UNEP used the AR5 scenarios database for their quantitative assessment, and that these scenarios are deemed technologically and economically feasible. He added that, in the literature, there are studies available that produce the same kind of scenarios but limit temperature increase to 1.5 °C above pre-industrial levels by 2100. The latter scenarios were not contributed to the AR5 database. An assessment of these scenarios was taken into account in the 2014 *Emissions Gap Report* and previous editions, but not in the same way as for 2 °C scenarios. He said that **in principle, the same methodology could be applied to the smaller set of 1.5 °C scenarios,** with some caveats: these scenarios all include a **temperature overshoot**; they achieve the target with **approximately 50 per cent probability**; and the scientific basis will be weaker because of the limited amount of 1.5 °C scenarios. In response to this question, an expert provided emission benchmarks for 1.5 °C scenarios based on the *Emissions Gap Methodology* to the SED co-chairs.

162. In response to a question by one Party about **which technologies are the most promising** for achieving negative emissions, an expert indicated that these are predominantly the **sustainable production of bioenergy, CCS** and **increased forest cover**. He underlined that UNEP did not assess these options, but noted the need to assess the feasibility of the assumption that these technologies will be available at scale when needed. Another expert explained that WGIII explored the consequences of the unavailability or the limited availability of these technologies. He stressed that **CO_2 removal technologies are essential in achieving negative emissions**, which serve two purposes: they are necessary because of historic emissions; and more importantly, in the second half of the century, they will **compensate for those non-CO_2 gas emissions that cannot be reduced to zero**. WGIII explored a comprehensive range of technologies and the consequences of the unavailability of CO_2 removal technologies, which would mean that emissions should be more significantly reduced in the short-term in order to achieve a relatively cost-effective pathway. Another expert explained that the IEA scenarios would fall within the lower end of those included in the *Emissions Gap Report*, with rapid reductions in the short-term, because IEA experts are uncomfortable with assuming massive reductions with negative emissions later in the century. However, she noted that IEA scenarios cover the period up to 2040 or 2050, by when CRD technologies will not have been introduced yet, but the design of the scenario makes assumptions about what will happen beyond these dates. On prospects for the CDR technology, she said it is a question of combining bioenergy and CCS, noting that at present, very slow progress has been made with CCS itself, let alone coupling it with bioenergy. She therefore underscored the **need for significant progress on CCS**.

163. A Party asked about the meaning of the term '**societally desirable adaptation**' in the *Adaptation Gap Report*, since adaptation is often not a choice. An expert explained that the term is based on the WGII report, which describes how to move from a level of adaptation that is technically and economically feasible, to what will actually happen on the ground. She noted that some communities or groups may choose to tolerate a higher level of climate change impacts because of different preferences regarding the adaptation target.

164. A Party asked if the figure of 90 per cent of adaptation funding going to developing countries mentioned by one of the presenters includes national and regional funds, as well as private sectors funds, at the national level. An expert clarified that the figure comes from a study of the Climate Policy Initiative, and includes

developed and developing countries' funding for adaptation, including that from national and regional development banks.[28]

165. A Party asked about the **cumulative impacts of the pledges made at the September 2014 United Nations Climate Summit** in relation to mitigation and adaptation. An expert stated that the United Nations office in charge of the summit is trying to set up a tracking system of the many pledges made, while noting the challenges of doing so because the pledges are often not concrete commitments and are not comparable, and their additionality is difficult to assess. Another expert added that the summit should be seen within a process that aims to build momentum on the road to Paris, and that assessing individual steps separately may not give an accurate picture, as follow up action may be taken in the future.

166. A Party asked a question concerning WHO figures that indicate that with 1.5 °C warming, the **number of children at risk of stunting will increase by more than 6 million by 2030** even with high economic growth. In response, an expert confirmed that this can be considered conservative since it does not take into account climate-related disasters and their potential impacts on food production and prices, implying that the projected increase in stunting is conservative.[29] The expert further clarified that the WHO looked at each health outcome at a time so the total aggregate impacts were not estimated.

167. A Party asked about the long-term **physical limits of the potential for negative emissions**. He queried whether relying heavily on negative emissions during this century could lead the sinks to be "entirely filled up", thereby prejudicing future generations after 2100. An expert said he did not know the answer but that he would look it up and provide the required information by the next day. Another expert explained that to determine the physical limits to negative emissions, one needs to take into account the fact that the oceans will lose part of the previously absorbed CO_2. Experts provided further information indicating that, to date, there are only rough estimates of the total global storage capacity. Estimates indicate that the capacity is significantly larger than storage needs in low GHG level stabilization scenarios up to 2100. Geological reservoirs could store several thousand GtC, the oceans a few thousand GtC in the long term, and the land may have the potential to store the equivalent to historical land-use loss of 180 ± 80 GtC (see also WGI Table 6.15, page 549 for physical potentials of removing CO_2 from the atmosphere).

168. Noting that by the end of 2100, non-CO_2 gases will have a larger share of global emissions, a large portion of which will come from agriculture to meet the demands of a growing population, a Party asked whether strategies exist to **combine the need for agriculture to adapt to climate change and to reduce its emissions**. An expert clarified that all scenarios that predict a lower global level of emissions feature a larger share of agricultural emissions and an important share of non-CO_2 emissions, which is why to achieve zero net emissions, negative emissions have to be factored in, because "we do not know how to produce food without emitting". FAO aims to achieve the three objectives of producing more food, adapting to climate change and contributing to climate change mitigation through CSA.

169. A Party asked for an indication of **which of the results presented** during part 2 of SED 4-1 **come from the AR5, and which do not**. An expert indicated that the WHO estimates were published after the IPCC cut-off dates and were therefore not part of the assessment, although the IPCC authors were aware of the work being done.

170. A Party asked **how the adaptation gap is going to be addressed**, adding that adaptation is a pressing need for developing countries. An expert said the AR5 clearly indicates that while adaptation and mitigation act at different timescales we need to work on adaptation, mitigation and development at the same time. Another expert stated that to ensure that the adaptation gap is filled, we should first ensure that it is as small as possible, and that will be achieved through progress in mitigation. He emphasized the need to "act now on adaptation", underlining the need for communities to "learn by doing". Another expert added that one of the aims of the *Adaptation Gap Report* is to generate discussions on this issue. She stated that "there is no question there is such

[28] Climate Policy Initiative. 2014. *Global Landscape of Climate Finance*. Available at <http://climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2014>.

[29] World Health Organization. 2014. Quantitative Risk Assessment of the Effects of Climate Change on Selected Causes of Death, 2030s and 2050s. Available at <http://apps.who.int/iris/bitstream/10665/134014/1/9789241507691_eng.pdf>.

a gap", expressing the hope held by UNEP that the report can generate a more strategic global thinking on adaptation and follow up with more specific analysis.

171. A Party made a comment on the limited carbon budget, calling on those countries that have "the capacity to do more, to do more", stressing that **the lesser the budget is, the greater the need to focus on the principle of common but differentiated responsibility**. An expert said the mitigation analysis in the *Emissions Gap Report* is done at the global level and does not interfere with the application of the Convention's principles. He added that the report also points to opportunities across sectors and to co-benefits that will drive action at various levels.

172. A Party asked if the World Bank's findings on **commoditizing carbon** are cost-effective in developing countries, which often have single commodity economies, and/or do not have mature markets. In relation to setting the price of carbon, he also asked whether the World Bank would seek to interfere with the market price or impose restrictions, stressing the freedom of the markets. An expert emphasized that the World Bank refers to "pricing carbon" as a generic phrase, aware of the fact that each country will pick the instrument that is best suited to the national circumstances, either a tax or a market. He referred to the Partnership on Market Readiness, which is a grant-based global partnership of developed and developing countries that provides funding and technical assistance for the collective innovation and piloting of market-based instruments for GHG emission reduction. He said the partnership also provides a platform for technical discussions of such instruments to spur innovation and support implementation. He added that in countries with weak institutions and low income, carbon taxes are much simpler than market-based instruments. He emphasized that all the instruments aim to raise revenues, which can be used to alleviate the shock of fossil fuel subsidy reforms, as has been the case in Ghana and Indonesia.

173. Commenting on a presentation that indicated that **poverty is decreasing**, one Party questioned the veracity of this finding. An expert confirmed that extreme poverty has been reduced in the past 20 years. The international poverty line is set at USD 1.25 per day in purchasing power parity; 42 per cent of the world's population was below that line 20 years ago. Today, this has been reduced to 17 per cent. He pointed to some caveats to this finding, including that poverty cannot be described solely through purchasing power as it is more complex, and that significant regional differences in poverty levels exist.

174. On energy and climate change, one Party commented that **investment in fossil fuels is still dominant** because it is a sustainable supply of energy and does not require subsidies on the production side. On **carbon intensity**, the same Party asked how to classify the carbon intensity of various energy sources, such as coal and gas. An expert welcomed the focus on carbon intensity, noting that it helps illustrate "what you need to do to make the transition" to a low-carbon economy rather than the goal itself. She added that one should look at the end uses of energy rather than examine the carbon intensity of various fuels. The power sector is projected to decarbonize rapidly because there are many choices for power generation. In the IEA models, the average emission intensity of the power sector goes below that of natural gas generation in the mid-2020's and continues downwards, led by new investments in low- or zero-carbon power generation. Changes in carbon intensity in the transport sector are much slower.

175. Noting that many developed **economies are driven by taxes on fossil fuels** that provide a major source of revenue, a Party asked how reduced demand for fossil fuels may affect these economies. An expert stated that the Organisation for Economic Co-operation and Development (OECD) is currently carrying out some research on how other policy areas than energy and climate will be affected by this transition and whether they support the transition, including tax and trade policies. The expert stated that a paper on this matter should be released in 2015.

176. A Party noting that scenario RCP8.5 projects an increase in temperature of 4–5 °C, asked for **clarification about the reference to a 6 °C scenario and its basis**. An expert explained that the reference to 6 °C is a long-term stabilization level rather than a 2100 level.

177. A Party asked about strategies to address **energy poverty**. An expert pointed to an IEA analysis that found that providing universal access to basic electricity for the 1.3 billion people who do not have it would

imply an increase of less than one per cent in global emissions.[30] She stressed that meeting these basic energy needs should therefore "not be an excuse" for very large emission increases. Another expert pointed to a World Bank report on the co-benefits of climate policies, which indicates that the energy poor use biomass with very bad health consequences, batteries or costly generators.[31] He added that providing clean sources of energy to these people therefore has significant development gains and should be one of the priorities of the energy sector.

178. A Party asked WHO to clarify its reference to "**uninhabitable places**", stressing that his country was very uninhabitable. An expert stated that some countries had done a "great job" of making themselves very comfortable, reiterating the point made by another expert earlier on the need to address mitigation, adaptation and development simultaneously. She called on other countries to learn from those countries living with very high temperatures, stressing the need to facilitate lessons learned across countries, taking into consideration various development contexts.

179. A Party asked FAO about the **potential savings that could be generated by changing lifestyles and reducing food consumption and food waste**. The same Party asked about the impacts of ethanol production on food security and its carbon footprint. An expert underlined that the carbon footprint of bioenergy varies greatly depending on the biomass used, the country where it is produced or the technology used. He stated that it is difficult to generalize, but that the carbon footprint of bioenergy generally is decreasing. There could be value in developing technologies now that will have a reduced footprint in the future. On the impact of bioenergy production on food security, he said this is a very complex question and referred to the report of the High-Level Panel of Experts on Food Security and Nutrition, which was prepared at the request of the Committee for World Food Security.[32] The report indicates that the impacts of bioenergy on food security are very diverse and depend on the area of production of biofuels, but also on the timescale used. He underlined that in some countries, bioenergy production can have an impact on food prices, but it is also is a driver of development and can lift people out of poverty and reduce energy poverty. He added that modern forms of biomass can be healthier and more efficient for a lot of uses, including in agricultural production. Noting that food demand is projected to increase by 60 per cent while the population is projected to increase by 30 per cent, he emphasized the need to limit demand through changes in diets and lifestyles. He stressed that it is more difficult to act on consumption than on production patterns.

180. A Party asked for confirmation that the AR5 indicates that **mitigation** action would come with important economic and social **co-benefits** and increases in energy security. Noting that immediate mitigation action is required in 1.5 °C scenarios, he asked if this would imply that the co-benefits of mitigation action would materialize earlier in these scenarios than in 2 °C scenarios. An expert said the co-benefits of mitigation action are clear, but **challenges exist in terms of measuring and defining them**. On the differences in the materialization of co-benefits in 1.5 °C and 2 °C scenarios, he said he was not aware of any study that examined this question.

181. A Party referred to the IEA presentation outlining emission reduction measures at zero GDP cost, in particular calling for the **removal of inefficient fossil fuel subsidies** which could reduce post 2020 emissions by about 12 per cent, adding that this can often bring a GDP benefit. He pointed to recent developments on this issue within the Group of Twenty (G20) and the Asia-Pacific Economic Cooperation (APEC) forum and in the post-2015 development agenda negotiations. An expert welcomed the developments mentioned, noting that they are success examples that provide an incentive for other countries to also remove fossil fuels subsidies. He explained that originally, such subsidies were generally put in place to help the poor access energy and help industry develop and create jobs. These two objectives can be achieved much more efficiently through other measures, for example with cash transfers for the poor, infrastructure development, or decreases in taxes on industry. Carbon pricing would make little sense in a place with massive fossil fuel subsidies, where the first step should be subsidy reform. In all cases, there is a focus on the poor and ensuring that they benefit from the

[30] IEA. 2011. Energy for All: Financing Access for the Poor. Available at <http://www.worldenergyoutlook.org/media/weowebsite/energydevelopment/weo2011_energy_for_all.pdf>.

[31] World Bank. 2014. Climate-smart Development: Adding Up the Benefits of Actions that Help Build Prosperity, End Poverty and Combat Climate Change. Available at <http://documents.worldbank.org/curated/en/2014/06/19703432/climate-smart-development-adding-up-benefits-actions-help-build-prosperity-end-poverty-combat-climate-change-vol-1-2-main-report>.

[32] Available at <http://www.fao.org/cfs/cfs-hlpe/reports/en/>.

reform. Another expert added that fossil fuel subsidy reform is a cost-effective measure for many countries, emphasizing that often the reform will be triggered by non-climate benefits.

182. A Party noted that the **emission-intensity is agreed inside the agricultural sector** and is well understood outside that sector. He asked about relevant FAO work on the use of emissions per unit of food and goal setting.

183. A Party asked **how important the Paris agreement is to get a switch in energy investment towards the decarbonization needed to get the world on a 2 °C pathway**, in particular to materialize the 80 per cent cost-neutral investments that were mentioned. An expert said the IEA sees the Paris agreement as very important, especially in the shift in investments in long-lived infrastructure, where investors need a long-term signal that such investments will be 'smart'. In relation to cost-neutral measures that can drive emission reductions before 2020, she stated that the Paris agreement can also play some role in providing an incentive for all actors to take early action if they know that stringent targets will be set in the near future, but action should happen with or without an agreement.

184. A Party asked about the importance of the **decarbonization of the electricity sector for limiting warming to 2 °C above pre-industrial levels**. Noting that in IPCC scenarios limiting global warming below 2 °C, this decarbonization happens around 2050, he also asked when the carbon intensity of this sector approaches zero in the IEA models. An expert stated that the IEA model indicates that electricity needs to be largely decarbonized by 2050, so under the same timeframe as that indicated by the IPCC in the AR5, adding that this will underpin the decarbonization of other sectors.

185. A Party referred to the **difficulty of defining adaptation funding**, asking if disaster relief would be considered adaptation funding, and what types of public and private funding could be considered as adaptation funding. He also asked for clarifications regarding the limitations and uncertainties related to the cost estimates of adaptation. An expert indicated that **disaster relief is not considered as adaptation funding** in the UNEP *Adaptation Gap Report*, which only includes funding for adaptation that is qualified as 'significant' or 'principal', as defined by the OECD database. He added that **funding for disaster risk management is increasingly being included** in estimates of adaptation finance flows. He recognized that there are high uncertainties in the cost estimates of adaptation because of the little data available to assess the effect of the measures. Although we are at the early stage of costing adaptation, a lot of progress has been made to lower these uncertainties. He also specified that private sector finance was not included in the estimates in the UNEP report because of the **inability to track private sector activities in adaptation**. Another expert emphasized that there are great **differences among sectors in relation to where the funding is going**. For example, only three per cent of the Least Developed Country Fund resources are going to the health sector. Another expert explained that the WGII report does not contain an adaptation gap dollar figure because many investments can be legitimately linked to adaptation or to another objective. To recognize this diversity of objectives, the IPCC decided that it was best not to identify a particular number.

186. A Party asked about the **reliance on nuclear power to achieve 2 °C** scenarios and negative emissions. An expert indicated that the WGIII assessed the impacts of the changes in the technology portfolios on the mitigation costs in figure 17.15 of the WGIII report. It found that a **moderate phase out of nuclear power can easily be substituted by renewables** because it is a flat optimum. However, there are multiple pathways to achieving low stabilization limits in a cost-effective way, for example through high energy efficiency and renewable energy, or through high shares of nuclear and CCS. He underscored that CCS is an exception, as it is particularly important in combination with bioenergy. He added that CCS technology has two functions: it prolongs the life of fossil fuels; and more importantly, it plays a role in producing negative emissions that counter historical emissions and emissions in other sectors that cannot be reduced to zero. Another expert explained that in the IEA 2 °C scenario, nuclear energy plays an important but supportive role, as it is part of the low-cost package.

187. A Party asked about the **release of large GHG reservoirs associated with hydropower generation**. An expert pointed to the *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*,[33]

[33] IPCC. 2011. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Available at <http://srren.ipcc-wg3.de/report>.

which indicates that the emissions released from the reservoirs depend on what was on the land that was flooded by the reservoir, but that they would be quite small compared with the emission reductions achieved through hydropower.

188. Noting that to guide the next review the IPCC may conduct a paper on agriculture, climate change and food security, a Party asked **what aspects of the AR5 would be a valuable input to such a paper**, and what the **primary research gaps** are in this space.

189. A Party said that adaptation and mitigation should be put in the broader context of finance and technology argued that **it is optimistic to state that achieving the 2 °C pathway is technically and economically feasible**, emphasizing that economic and technological resources are distributed unevenly at the regional and national levels, and asked if this was considered in the analysis. An expert explained that the World Bank looks at the difference between the economic costs and the financing needs, stressing that some of the measures that have net benefits in economic terms may require a lot of up-front investment and less operational costs. He said that if the constraints are financial, these measures may be very difficult to put in place. As a result, financing instruments will play a key role in the transition to a low-carbon economy, especially in a world where we are still lacking USD 1.0–1.5 trillion per year in investments. He indicated that the World Bank is working to provide solutions to this investment gap, most probably through a package of measures. He added that carbon pricing could provide some of the financing that is needed to achieve the climate goal. Another expert underlined that the analysis carried out for the *Emissions Gap Report* is carried out at the global scale, however, all the editions of the report have included a chapter on what can be done, using examples at the country level. Yet another expert added that the WGIII chapter on regional costs and feasibility indicates that it is not just an issue of technical feasibility, but also a question of regional distribution of costs. He pointed to remarkable differences across the regions, stating that it all pertains to the distributional aspect of the whole problem and how to organize transfers and financial support.

190. A Party asked if an **analysis of the barriers to adaptation technology transfer** had been carried out, and if experts could provide some recommendations on how to overcome these barriers. An expert pointed to the World Bank's *Green Growth Report*,[34] which stresses that transfer is not the only issue, emphasizing the important need for technology to be adapted to the local context in order to be effective. He also stated that trade barriers can sometimes constitute a significant obstacle to technology transfer. Another expert said there is expert judgment that goes into the IEA scenarios on how quickly different technologies would be taken up in different regions. She added that just because a measure could be taken at zero GDP cost, it does not mean that it would be easily implemented, stressing that some capacity and finance issues would need to be overcome. Yet another expert clarified that the *Adaptation Gap Report* refers to a barrier analysis of technology transfer. She indicated that the technology chapter primarily builds on lessons learned from the technology needs assessment project funded by the Global Environment Facility (GEF), which UNEP helped implement. The main barriers identified are: financial barriers; regulatory and legal frameworks; technical barriers to the development and transfer of technology; and institutional and organizational barriers.

191. A Party asked if there was **anything else that should be done in the UNFCCC process, aside from negotiating the Paris agreement, to speed up the transformational change** required to drive down emissions. An expert encouraged the UNFCCC to **look at the issue in a more holistic way, and not only focus on emission reductions targets every few years but also on the energy sector transformation that is required** to ensure that the needed infrastructure is in place. Another expert called for an **increased focus on adaptation and development**, underlining the tendency to focus on one element of the problem at a time and stressing the need to "look at the full picture".

192. A Party asked about the **impacts of air-borne desert dust particles**, which are considered the primary cause of premature death in the Middle East, and are projected to increase with climate change and the resulting increased desertification. He also asked if any analysis has been carried out on the possible feedback of desert dust particles on climate change. An expert indicated that WHO is well aware of the health impacts of desert dust particles, but that there is relatively little literature on the issue. She noted, however, that more research is currently underway for various regions, and that the literature is becoming large enough to be assessed. Another

[34] World Bank. 2012. Inclusive Green Growth: The Pathway to Sustainable Development. Available at <http://siteresources.worldbank.org/EXTSDNET/Resources/Inclusive_Green_Growth_May_2012.pdf>.

expert pointed to the IPCC Special Report on *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*,[35] which touched on the health impacts of desert dust particles, but was unable to distinguish a separate climate change cause for these impacts. He also mentioned that WGI examined the impacts of dust as a climate forcer, but did not carry out a separate analysis of desert dust. He said these are opportunities for future research and assessment.

193. A Party questioned the fact that **floods are disproportionately affecting the poor in Mumbai**, as presented by the World Bank. He explained that most of the impacts of floods in Mumbai are due to the inadequacy of the services provided, such as sanitation, as well as heavy rain coinciding with high tides. He added that with improved services, another Indian city has had some success in reducing the impacts of flooding. An expert recognized that, in both developed and developing countries, the land markets are pushing people out onto land that are exposed to flooding. He pointed to the success of disaster risk management when a hurricane hit India in 2013, demonstrating that cheap solutions, taking into account the local context, can save thousands of lives.

194. A Party asked if an assessment of the national and local governments' efforts to minimize vector-borne and water-borne impacts after extreme events has been carried out.

D. Part 3: Information from United Nations and international organizations, and from processes under the Convention

1. Presentations by experts

195. Mr. Juan Hoffmaister, Adaptation Committee Co-Chair, presented on enhanced adaptation action in the context of the 2 °C limit to global warming. He listed the three workstreams of the Adaptation Committee's 2013–2015 workplan, namely: **technical support and guidance to Parties on adaptation action**; **technical support and guidance to Parties on MOI**; and **awareness-raising, outreach and sharing of information**. While noting that the Adaptation Committee's 2013–2015 workplan does not include a specific focus on the long-term global goal, he stated that the Cancun adaptation framework is flexible enough to respond to the issues emerging in the light of this goal, and that a new flexible workplan is being developed for 2016 and beyond.

196. He explained that the aim of NAPs was to reduce vulnerability to the impacts of climate change, by building adaptive capacity and resilience, and facilitate the integration of climate change adaptation into new and existing policies, programmes and activities, and development planning processes and strategies, within all sectors and levels.

197. Mr. Hoffmaister then described some experiences with NAPs, including: when preparing their national communications, most countries have already conducted an analysis of observed changes in the climate system, applied climate scenarios for projections and conducted vulnerability assessments; many LDCs can build on results from the assessments they have undertaken for their National Adaptation Programmes of Action; and Parties have reported challenges in using the latest IPCC scenarios to formulate and implement NAPs, as well as concerns regarding their applicability to specific and/or local contexts such as mountainous regions.

198. He mentioned **lessons learned in the formulation and implementation of NAPs** and national development planning, stressing the importance of an appropriate national mandate and high-level coordination mechanisms for adaptation. Among the many programmes and activities that countries have been, and are supporting, that already contribute to the objectives of the NAP process, he pointed to sector budgets, and projects aimed at alleviating poverty through enhancing the resilience of communities at the national and local levels to climate change risks and impacts. He underlined that some bilateral organizations are receiving very few requests from countries for support for the NAPs process, in contrast to the high number of requests for support under the NAP global support programme.

199. In addition, he reported that: organizations and agencies need to consider their organizational mandates, set-ups and resources in the light of the long-term nature of the NAP process; for many Parties, there is a lack of

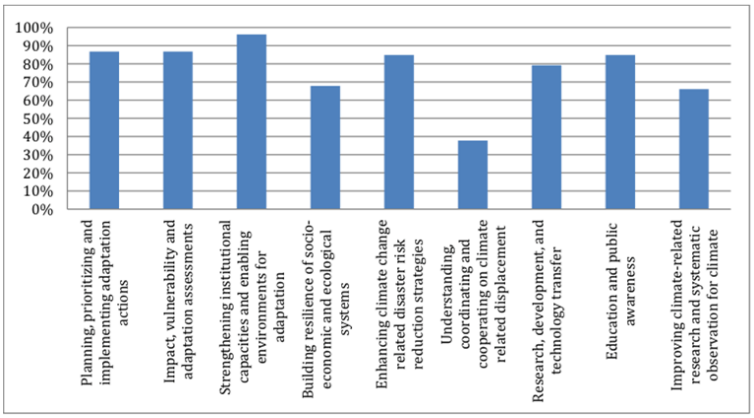
[35] IPCC. 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Available at <http://www.ipcc-wg2.gov/SREX/>.

clarity on procedures for applying for funding from the Least Developed Counties Fund (LDCF) and the Special Climate Change Fund (SCCF) for the NAPs process; and since both funds are based on voluntary contributions, some Parties suffer from inadequate and unpredictable financing that hinders further scaling up and mainstreaming adaptation into national development planning.

200. On the **monitoring and evaluation of adaptation**, he stressed that: appropriate monitoring and evaluation frameworks are needed, relevant to needs and tailored to country circumstances; due to the context-specific nature of adaptation, a common set of global indicators is not useful; national-level assessments can play a different role in measuring adaptive capacity from subnational or project-based assessments, for example, to measure the degree of coordination and integration of adaptation in national priorities; a positive learning environment is important; and planning and allocation of resources, both technical and financial, are key for effective monitoring and evaluation systems.

Figure 88

Mapping and analysis of support from United Nations agencies and regional institutions on adaptation (2013/2014)



Source: Slide 8 of the presentation by Mr. Juan Hoffmaister (Co-Chair of the Adaptation Committee (AC)), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_ac_co-chairs_sed4-2_feb8.pdf>. The figure indicates areas of support provided by organizations and United Nations agencies that share information with the Adaptation Committee (for details, see Adaptation Committee document AC/2014/7, available at < http://unfccc.int/8012.php>).

201. In closing, he presented a graph illustrating findings from mapping and analysis of support from United Nations agencies and regional institutions on adaptation, which indicates that all organizations and United Nations agencies that share information with the Adaptation Committee are providing support to strengthen institutional capacity, but that other issues, such as those associated with climate-related displacements, are not receiving support across the whole system (figure 88).

202. Mr. Paul Leadley, Coordinator of *Global Biodiversity Outlook- 4*,[36] delivered a presentation on connecting biodiversity with climate change mitigation and adaptation, which was prepared in collaboration with Mr. David Cooper, Director of Science, Assessment and Monitoring, CBD, and Mr. Phillip Williamson, Lead Author of *An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity*.[37] The main messages of his presentation were that: many organisms and ecosystems are already impacted by recent climate changes and additional change will exacerbate impacts; thresholds are often difficult to identify; **biodiversity can play an important role in increasing climate change resilience**; and **pathways to remain within 1.5 °C or 2 °C** of warming above pre-industrial levels **will require careful management to conserve biodiversity and ecosystems**, as well as to optimize their contribution to climate mitigation and adaptation.

[36] Secretariat of the Convention on Biological Diversity. 2014. Global Biodiversity Outlook. Available at <http://www.cbd.int/gbo4/>.

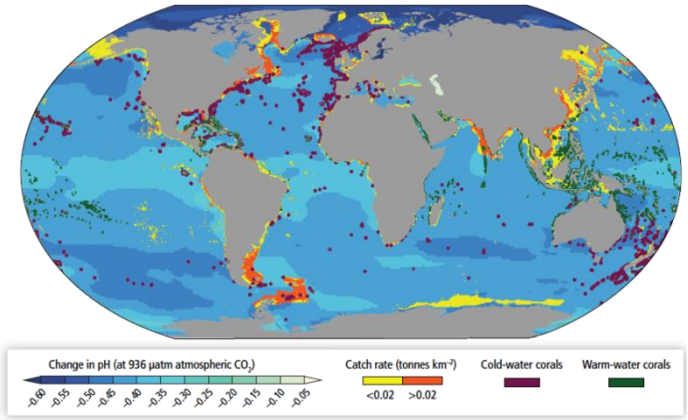
[37] Secretariat of the Convention on Biological Diversity. 2014. An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity. Available at <http://www.cbd.int/doc/publications/cbd-ts-75-en.pdf>.

203. He explained that ocean acidification is a direct response to rising atmospheric CO_2, involving more dissolved CO_2, bicarbonate ions (HCO_3^-) and hydrogen ions (H^+) (i.e. lowered pH) but less carbonate ions (CO_3^{2-}). He said marine organisms can react to any of these changes, and different organisms react in different ways. He pointed to the interactions with: other climate-related stressors (e.g. warming, hypoxia); indirect pH effects (e.g. increased metal toxicity); food and nutrient availability; and biotic factors (e.g. food web changes, competition). While noting the pole-ward migration of marine species due to temperature changes, he underlined that ocean acidification reduces species' ranges.

204. On the **difference between CO_2 levels associated with 1.5 and 2 °C warming**, he stated that ocean acidification already causes impacts on marine species, and that any additional increase of atmospheric CO_2 and other stressors will progressively increase the ocean acidification risk to biodiversity (figure 60 above).

205. On the **natural capacity of marine organisms to adapt**, he noted that Palaeolithic-evidence shows natural ocean acidification events, albeit at much slower rates than today, which caused the extinction of many benthic species. Some experiments show that there is capacity to adaptation to lower pH, but it is very limited. Natural experiments around CO_2 vents in shallow seas show that there is a dramatic loss of biodiversity. He added that even if some species can adapt, ecosystem changes will occur, and there will also be corrosion of unprotected carbonate structures (e.g. cold-water corals) in unsaturated waters. Mr. Leadley stated that the impact of ocean acidification on warm-water corals is also of concern, since the lower pH affects their ability to calcify and hence population recovery from bleaching. He underlined that reef loss affects many other species and increases the impacts of sea-level rise. Warm-water coral reefs are already under stress, with more than 50 per cent currently in poor health, while cold-water corals are at risk from the increasing area of seafloor experiencing aragonite saturation of less than 1.0. He said that protecting coral reefs requires combining global action (i.e. CO_2 emission mitigation for climate and ocean acidification) and local action (i.e. the protection of herbivorous fish and pollution controls) (figure 89).

Figure 89
Species vulnerable to ocean acidification – of high socioeconomic or ecological importance



Source: Slide 9 of the presentation by Mr. Paul Leadley (Convention on Biological Diversity), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2_cbd_sed4-2_feb8.pdf>. The figure indicates known locations of cold- and warm-water corals, depicted on a global map showing the projected distribution of ocean acidification under RCP8.5 (pH change from 1986–2005 to 2081–2100)

206. Mr. Leadley then focused on **forests**, noting that they are being negatively impacted by climate change sooner than had been anticipated, and that impacts vary substantially across tree species and regions (AR5, WGII chapter 4). He stressed that: reinforcing species and genetic diversity of trees can enhance the adaptive capacity of forests to climate change; reducing deforestation can contribute both to climate change mitigation and biodiversity protection; using diverse tree species mixes or natural regrowth for restoration can contribute to climate change mitigation and biodiversity protection; planting forests could make important contributions to future bioenergy, but if they replace primary forest they have negative impacts on biodiversity and medium-term climate balance.

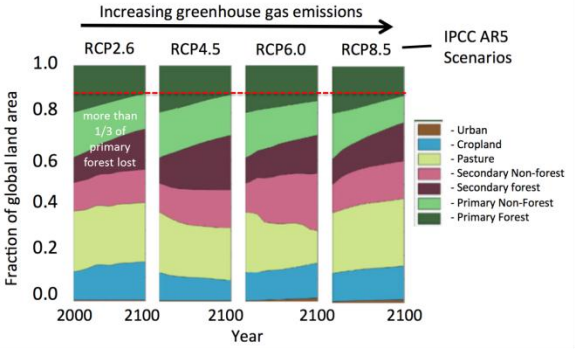
207. He underscored that since the **conversion of tropical forests to plantations** has very large, long-term, negative impacts on biodiversity and soil carbon stocks, leaving tropical forests intact is 'a win-win', hence the

importance of REDD plus.[38] He then explained that the *Global Biodiversity Outlook* indicates poor progress on halting deforestation of primary forests globally, with the exception of a 70 per cent reduction in deforestation in Brazil. He added that progress can be made but depends on, inter alia: good governance; publically available monitoring of deforestation; public awareness; the expansion of protected areas and demarcation of indigenous lands; incentive measures; and willingness to move forward.

208. On **reforestation**, Mr. Leadley underscored that, if appropriately done, active and passive forest restoration can have large positive benefits for climate mitigation, biodiversity and ecosystem services. He explained that while massive reforestation efforts are made globally, some are carried out with monoculture and exotic species, and hence have poor biodiversity benefits. While recognizing the complexity of optimizing co-benefits for biodiversity, climate mitigation and other ecosystems services for restoration projects, he stressed that new decision support tools can help evaluate trade-offs.

209. Mr. Leadley then examined the **primary land-use scenarios** associated with the four of the RCP scenarios, highlighting that in **RCP2.6, more than a third of primary forests was lost**, and that none of the other RCP scenarios had a positive impact on primary forests (figure 90). He stated that the other scenarios are "not very good for primary forest either" due to the negative effects of climate change on primary forest.

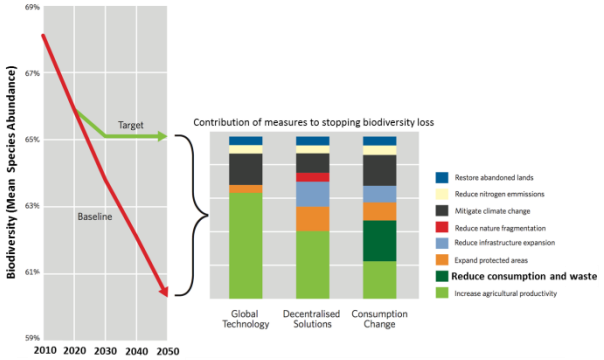
Figure 90
Primary land-use scenarios associated with the four representative concentration pathways scenarios



Source: Slide 13 of the presentation by Mr. Paul Leadley (Convention on Biological Diversity), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2_cbd_sed4-2_feb8.pdf>. The figure shows changes in the global land use during the course of this century expressed as fractions of total land area for various RCPs. The red horizontal line indicates the remarkably similar loss of primary forests in all four scenarios by 2100.

Abbreviations: RCP = representative concentrations pathways. IPCC AR5 = Fifth Assessment report of the Intergovernmental Panel on Climate Change.

Figure 91
Achieving the Convention on Biological Diversity 2050 Vision and ties with Sustainable Development Goals



Source: Slide 14 of the presentation by Mr. Paul Leadley (secretariat of the Convention on Biological Diversity (CBD)), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2_cbd_sed4-2_feb8.pdf>. The figure shows current trends in biodiversity loss (left panel, red line) and the CBD conservation target (green curve). The right panel shows three alternative scenarios of policy measures (global technology, decentralized solutions, and consumption change), each achieving the same conservation target while also reaching climate as well as sustainable development goals. The importance of reducing consumption and waste was underscored.

210. He therefore called on the IPCC, the Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services (IPBES) and the UNFCCC to work together to meet climate and biodiversity targets and other sustainable development goals, in particular to: stop biodiversity loss by 2050; meet the Millennium Development Goals, with a focus on eliminating hunger; and keep global warming below 2 °C above pre-industrial levels. He presented three such possible alternative scenarios that will meet all the goals together, based on the IMAGE model, for achieving the 2050 Vision, emphasizing the importance of reducing consumption and waste (figure 91).

[38] In Decision 1/CP.16, paragraph 70, the Conference of the Parties encouraged developing country Parties to contribute to mitigation actions in the forest sector by undertaking the following activities: reducing emissions from deforestation; reducing emissions from forest degradation; conservation of forest carbon stocks; sustainable management of forests; and enhancement of forest carbon stocks (REDD).

211. Mr. Sergio Zelaya, Special Advisor on Global Issues, UNCCD, gave a presentation titled "Desertification and land degradation and their impact on natural ecosystems and food security, a UNCCD response to the 2 °C target".

212. He presented some global facts on land, including that: global arable land represents 1/32 of the planet surface; **52 per cent of agricultural land is affected by degradation**; **land sector emissions amount to 6.2 Gt CO_2 eq per year**; **1.8 billion of the world's population in 2025 will be living with absolute water scarcity and two-thirds (or 5.3 billion) could live under water stress conditions**; **land degradation over the next 25 years may reduce global food production by up to 12 per cent**, and lead to an increase of as much as 30 per cent in world food prices; the world's drylands represent 40 per cent of total land mass, a third of the population, and 44 per cent of the food production system; 925 million people are hungry, including 80 per cent of small-holder farmers and the landless poor in rural areas; 40 per cent of interstate conflicts are associated with land and natural resources; and some 135 million people may be displaced by 2045 as a result of desertification.

213. After providing some definition of basic terms related to land and land degradation, he focused on the interaction between land and climate, underlining that **small changes in that interaction can cause larger global changes**. Pointing to AR5 findings, he explained that: dry areas are expected to increase in many parts of the world, increasing the current extent of semi-arid areas and the risks to the proper functioning of ecosystems; as the productivity and availability of land resources falls, so does adaptive capacity and resilience; and the unsustainable use of natural resources for food and energy causes land degradation locally, increases carbon emissions, reduces biodiversity and diminishes rainfall at multiple scales.

214. He pointed to common approaches to climate change mitigation and adaptation for addressing land degradation in drylands today and in non-dryland areas at risk. Noting that a large proportion of land ecosystems used for provisioning services is 'degraded', mostly due to the modes of use, he called for **non-degraded productive land, land under restoration in drylands and land at risk of becoming drier to be addressed** by exploring, identifying and further improving sustainable land management (SLM) methods and practices.

215. Mr. Zelaya explained that UNCCD adopts a holistic approach to land management and land degradation by aiming at **land degradation neutrality**. He outlined some benefits of land degradation neutrality, namely: its low cost, with an estimated average cost for land restoration of EUR 130 per ha or 0.45 Gt CO_2 eq while the economic rates of return of conservation, rehabilitation and SLM could reach 12–40 per cent; its multiple benefits, such as improved livelihoods in terms of food and water security, productivity increase and employment options; and its contribution to a low-carbon world, since the restoration of 12 million ha/a year could sequester 6.75 Gt CO_2 eq/year.

216. He underlined that land degradation neutrality is an ecosystem approach but that it is not a global target as it is still under negotiation, and each country can determine its level of ambition. Mr. Zelaya pointed to UNCCD COP decisions on the bottom-up target approach, noting their coherence with the UNFCCC process.

217. In closing, he outlined five opportunities for UNCCD to support Parties by: (i) providing support to the formulation of their INDCs in relation to key information on land use; (ii) integrating and combining sources of data for INDCs to assess the mitigation potential of existing plans and policies for land rehabilitation using IPCC default stock change and emission factors; (iii) setting up national land use mitigation targets and identifying their potential and co-benefits; (iv) focusing action on achieving land degradation neutrality as a starting point when reporting on INDCs implementation; and (v) providing land-based indicators common for reporting on climate change adaptation and mitigation, and on progress on land degradation neutrality and SLM.

218. Mr. Amena Yauvoli, SBI Chair, gave a presentation on supporting adaptation and mitigation action through capacity-building and education. He described the Durban Forum on capacity-building, which was established in 2011 by decision 2/CP.17, and whose mandate was expanded with decision 10/CMP.8 to cover issues relating to capacity-building under the Kyoto Protocol. The forum, which is organized by the SBI, has held three annual in-session meetings so far, with the next scheduled to take place during SBI 42, in June 2015.

219. The **Durban Forum aims to**: enhance the monitoring and review of the effectiveness of capacity-building; exchange experiences, good practices and lessons learned; provide an overview of capacity-building elements in the work of bodies established under the Convention and its Kyoto Protocol; and provide inputs to the review of the framework for capacity-building in developing countries. He underlined that the participatory

mechanisms of the Durban Forum are very broad based, and the agenda is usually driven by Parties through submissions on possible topics.

220. At previous meetings, Durban Forum participants have **discussed** ways to further enhance the monitoring and review of the effectiveness of capacity-building, the creation of an enabling environment, and capacity-building for adaptation and mitigation and gender mainstreaming. Mr. Yauvoli indicated that discussions held at each meeting of the Durban Forum are summarized in a report, which is forwarded for consideration to SBI.

221. He reported that **Durban Forum meetings are confirming that** there is a variety of activities to build capacity to mitigate and adapt to climate change that are embedded in mitigation and adaptation projects, and that bodies established under the Convention and its Kyoto Protocol are engaged in capacity-building activities, mostly at the regional level.

222. Among the **lessons learned** from the 2014 meeting of the Durban Forum, he highlighted the need to: build capacity to generate a higher level of social awareness of climate change and its impacts; actively coordinate stakeholders involved and identify the 'right' stakeholders and institutions to be trained to ensure that capacity-building efforts are effective; and enhance South–South and peer-to-peer cooperation to enable a strong cross-fertilization of ideas.

223. Mr. Yauvoli then described the **Dialogue on Article 6 of the Convention**, which was established in 2012 by decision 15/CP.18 under SBI. He explained that the Dialogue had held two annual in-session meetings so far, in 2013 and 2014, with the next scheduled to take place during SBI 42, in June 2015. The Dialogue on Article 6 of the Convention aims to provide a regular forum for Parties and other stakeholders to share their experiences, ideas, good practices and lessons learned regarding the implementation of Article 6 of the Convention. He noted that **participation in the Dialogue is broad-based**, and that the six elements of Article 6 of the Convention (education, training, public awareness, public participation, public access to information and international cooperation) are clustered into two focal areas that alternate on the Dialogue's agenda on an annual basis: the first area being education and training and international cooperation on these matters; the second, public access to information, public participation and public awareness, and international cooperation on these matters. He explained that discussions held at each meeting of the Dialogue are summarized in a report, which is forwarded for consideration to the SBI.

224. Among **messages emerging from the Dialogues**, he highlighted that: education and public awareness are fundamental for encouraging people to tackle climate change by changing their attitudes and behaviours towards climate-friendly lifestyles; climate change issues should be communicated in a manner that is understandable for all groups of society, attributable to daily life and does not create panic, but emphasizes opportunities; and the implementation of all elements of Article 6 of the Convention will contribute significantly to achieving the ultimate objective of the Convention and to implementing effectively adaptation and mitigation actions.

225. In concluding, Mr. Yauvoli underscored that **capacity needs to be built and education fostered in order to assess the adequacy of the 2 °C goal and the overall progress towards that goal**. He also said the Durban Forum and the Dialogue on Article 6 of the Convention can contribute to: promoting discussions among experts and practitioners; identifying lessons learned; replicating good practices and fostering action for emission pathways consistent with a 2 °C limit; and gathering information to support the review of the adequacy of the long-term global goal.

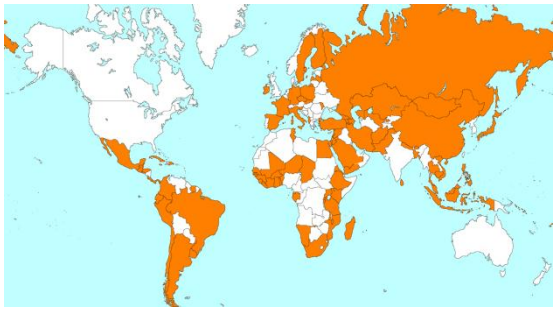
226. Mr. Jukka Uosukainen, Director, CTCN, gave a presentation on the development and transfer of technologies in the context of the 2 °C limit to global warming. He explained that, together with the Technology Executive Committee (TEC), the CTCN forms the UNFCCC Technology Mechanism, and is among the pre-2020 UNFCCC processes focusing on enhanced implementation. He added that while the TEC is the policy arm of the Technology Mechanism, the CTCN is the implementation arm, and aims to enhance action on the development and transfer of technology for action on climate change.

227. The CTCN mandate is to stimulate "technology cooperation and enhance the development and transfer of technologies to developing country Parties at their request". The CTCN offers the following three services: (i) providing technical assistance to developing countries; (ii) sharing knowledge and training; (iii) fostering collaboration on climate technologies, including linking climate technology projects with financing opportunity. The CTCN is hosted by UNEP, in collaboration with the United Nations Industrial Development Organization (UNIDO), and supported by 11 partner institutions with expertise in climate technologies.

228. Mr. Uosukainen indicated that as of 19 January 2015, 105 countries had selected their National Designated Entities (NDEs), stressing that the CTCN cannot render its services without an NDE and encouraging those countries who have not yet designated one to do so (figure 92).

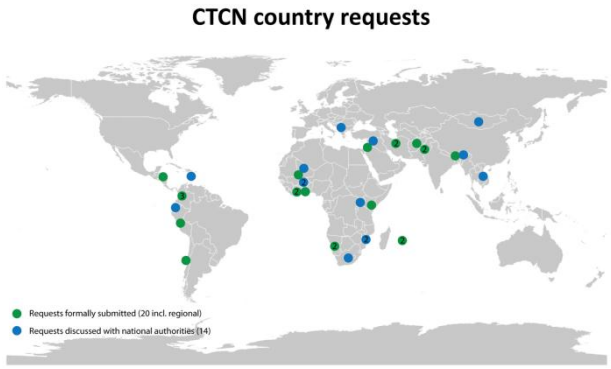
229. He described the **technical assistance** provided by the CTCN, stressing that it is: provided to developing countries upon their request; free of charge, with a value up to USD 250,000; both state of the art and locally-relevant expertise; provided to academics, the public, nongovernmental organizations or private entities; and for a broad range of adaptation and mitigation technologies.

Figure 92
Countries with designated national CTCN entities



Source: Slide 5 of the presentation by Mr. Jukka Uosukainen (Climate Technology Centre and Network), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/5_ctcn_sed4-2_feb8.pdf>. The figure shows a map of countries that have designated their national entities to the Climate Technology Centre and Network (80 developing countries).

Figure 93
Countries' requests to the CTCN for technical assistance



Source: Slide 8 of the presentation by Mr. Jukka Uosukainen (Climate Technology Centre and Network), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/5_ctcn_sed4-2_feb8.pdf>. The figure illustrates countries requests for technical assistance from the Climate Technology Centre and Network.

230. Mr. Uosukainen stated that through its network, the CTCN mobilizes policy and technical expertise from academia, civil society, finance and private sectors to deliver technology solutions, capacity-building and implementation advice to developing countries. He indicated that the CTCN had received 20 requests for technical assistance, some of which were already in the implementation phase, and that 14 additional requests are under discussion with national authorities (figure 93). He underlined the role of NDEs in coordinating the demands of their countries and explained that the assistance provided comes, at the moment, from the expertise of the 11 institutions that make up the consortium, but that the CTCN is looking to increase the number of its network members.

231. Mr. Uosukainen emphasized that the technical assistance provided by the CTCN is particularly quick, with expert teams set up in a couple of months and requests implemented within a year. He indicated that 72 requests (approximately 100 at the moment of writing this report) are anticipated in 2015, noting the need to maintain the balance between adaptation and mitigation requests, as well as among regions. He cited the examples of assistance provided to Colombia in relation to energy efficiency and renewable energy strategies, and to Iran on the design and manufacturing of photovoltaic solar cells. He underscored that the CTCN aims to link with all relevant activities under the UNFCCC process, such as the NAP and the technology needs assessment processes, in order to ensure coherence and coordination.

232. In closing, he underscored that: the TNA process and the work of the CTCN should be linked; the NDEs will play a key role, especially in bringing together all the relevant stakeholders; and technology support systems currently represent only a percentile of climate funding within the remit of the Convention, but it is fast growing.

2. General discussions

233. The ensuing discussion was guided by the following questions on theme 1 and theme 2 of the 2013–2015 review:

(a) Where has promising progress been achieved and what barriers to adaptation of which ecosystems, which agricultural systems, and which developing regions have been identified?

(b) What progress has been made in building capacity and educating on climate change? What are the main barriers to these efforts? What could be done to overcome these?

(c) What success stories exist in relation to national and regional actions that have enhanced the effectiveness of technology policies?

(d) What progress has been made on funding for climate action? What barriers and opportunities exist for the scaling-up of climate finance flows?

(e) Can ecosystems adapt naturally with respect to the transformation pathways compatible with a long-term global goal of 2 °C or 1.5 °C respectively? Which ecosystems are the most at risk? Which the least? What is the role of biodiversity for adaptation in general and which specific opportunities exist, such as ecosystem based adaptation?

(f) What role can capacity-building and education play in achieving the long-term global goal?

(g) Which transformation pathways compatible with 1.5 °C or 2 °C warming compared with pre-industrial levels are projected to threaten food production or offer the most opportunities?

(h) What barriers or opportunities to CSA and adaptation in the fisheries sector are projected to exist for emission pathways consistent with 1.5 °C and 2 °C warming compared to pre-industrial levels?

(i) What are the key opportunities for and barriers to adaptation that are projected to exist for emission pathways consistent with 1.5 °C and 2 °C warming compared with pre-industrial levels?

(j) What level of climate finance will be required to achieve the long-term global goal? What are the key factors that need to be in place to ensure that such a level is reached?

234. A Party asked about the **impact of land degradation on natural ecosystems and food security and linkages with the INDCs**. He noted that USD 1.7 billion will be required to achieve land degradation neutrality, and that INCDs are expected to clearly define the MOI in accordance with the Convention. He asked for clarification of the **role of INDCs in achieving land degradation neutrality**. Another Party asked about the **connections among actions aimed at protecting soils and halting land degradation, climate mitigation benefits and the price of carbon** and commented that the price of carbon would be higher in a world that is 1.5 °C warmer and that the higher price would thus have the co-benefits of halting land degradation. An expert explained that the target of 2 million ha of land restored proposed by UNCCD corresponds to the amount of land degraded annually. He added that the price of carbon used is based on the 2 °C scenario. He added that UNCCD is able to quickly assist those countries that wish to include the land component in their INDCs, pointing to challenges related to property rights and land tenure, and stressing that UNCCD would only use IPCC guidelines and methodologies for assessing the mitigation benefits. A Party further asked if, considering the USD 1.7 billion assessed by UNCCC, a link can be made with the financial mechanism under the Convention. He then asked if, at the next meeting of the SED, a GCF expert could provide information on the amount of finance available to support efforts to achieve land degradation neutrality. Mr. Zou Ji underlined that the Geneva meeting of the SED was its last.

235. A Party asked **how the CTCN plans to collaborate with the Durban Forum**, and if there are any capacity-building projects under the CTCN. An expert explained that he considers most of the CTCN activities to be capacity-building, underlining the importance of coordinating its work with the Durban Forum. He added that if requests for the services provided by the CTCN are not clearly defined then the CTCN works with the country in reformulating them, which is also a capacity-building process. He also pointed to an "incubator programme" for LDCs to help them define and identify their technology problems, which has already been used by approximately 10 LDCs. The expert also pointed to the organization by the CTCN of webinars that provide training on specific climate-related technologies.

236. A Party asked about the **impact of monoculture on biodiversity and genetic diversity**, noting that it may have climate mitigation benefits. An expert explained that, in many situations, genetic diversity provides many favourable outcomes and is useful in both tree plantation and restoration projects. He cautioned that "it is not always win-win", and that some species restoration projects will not provide the fastest carbon storage nor

the best resilience, hence the importance of support tools to evaluate the trade-offs between climate and biodiversity benefits.

237. A Party asked for **statistics regarding the amount of technology requests related to mitigation and those related to adaptation**, as well as information on the criteria used to prioritize requests. An expert replied that the 30 requests received so far by the CTCN are quite evenly distributed across regions and sectors. He said the CTCN has two sets of criteria for selecting requests. The first is an eligibility criterion, indicating that the request should support national climate efforts and support indigenous capacities in the country. The second criterion relates to prioritization in case the CTCN cannot serve all the requests received. In such cases, the CTCN is to ensure the balance between requests related to mitigation and those related to adaptation, as well as to serve LDCs and other vulnerable countries as a priority. He added that the CTCN currently has enough funds to serve all the requests received, but depends on bilateral funding from developed countries.

238. A Party noted that the presentation by the CBD had shown a clear difference in **impacts on ocean acidification and on coral reefs between 2 °C and 1.5 °C** of warming above pre-industrial levels. If there is a temperature overshoot, he asked how long, if at all, it will take for biodiversity to be restored. An expert indicated that if there is a temperature overshoot, which would be accompanied by a CO_2 overshoot, then the global water chemistry would take a very long time to recover, as shown by the Palaeo evidence (e.g. 10,000 years).

239. A Party asked for clarification on the CBD presentation regarding the modelling and **what is meant by reducing climate change, and whether it implies addressing global temperature increase or also other elements**. An expert explained that climate scenarios take into account emissions of CO_2, N_2O and CH_4 associated with all the different sectors, as well as other CBD targets, such as reducing deforestation, halting biodiversity loss, advancing human development, or ensuring sufficient food for everyone on Earth.

240. A Party pointed out that the workplan of the **Adaptation Committee does not have a specific focus on the long-term global goal**, and suggested that SED discussions be concentrated on the commitments under the Convention. While expressing his disappointment regarding the absence of a presentation on finance during SED 4, he asked if there are **initiatives under the Adaptation Committee on the consideration of commitments under the Convention relating to MOI**. An expert said that despite the absence of a specific reference to the long-term global goal in the workplan of the Adaptation Committee, which was adopted through a Party-driven process, it would be "difficult to argue" that NAPs are not contributing to the achievement of the long-term global goal. He stressed that it is up to **Parties to determine at the national level the level of risk they want to address**. On finance, he referred to ongoing work on adaptation finance carried out in collaboration with the Standing Committee on Finance, which examines national institutional arrangements, the NAP process and the challenges faced by countries in relation to access to finance and the integration of adaptation into national development plans.

241. A Party welcomed the use of the example of Brazil's efforts to reduce deforestation in the CBD presentation, but **underscored that tree mortality is increasing globally**, to some extent due to climate change, stressing that without global efforts to mitigate climate change, forests will continue to be threatened. An expert agreed, noting evidence showing that trees and forests are sensitive to temperature increases. He said that it is clear that the carbon stored in these protected areas is vulnerable to temperature increases, warning that with temperatures above 2 °C of warming, there could be very serious forest die backs in the Amazon.

242. A Party asked **which adaptation actions are the most urgent** to preserve coral reefs and food supply and protect biodiversity in the context of climate change and desertification, and **what kind of financial support is required** to promote adaptation and mitigate climate change impacts. An expert underlined that besides ocean acidification, coral reefs are also affected by coral bleaching and increased sea level, which are all impacts of climate change. He also pointed to local pressures on coral reefs, such as land-based pollution, overfishing, dangerous or disruptive fishing practices, and suboptimal coastal developments. He explained that countries can address these non-climate pressures through, inter alia, **reduced pollution and improved marine and coastal planning** in the short and medium term. He underlined that these measures will not bear fruit if they are not carried out in concert with global efforts to mitigate climate change. He also stressed the "enormous" benefits of protecting coral reefs, pointing to protection from erosion with a 97 per cent reduction in wave effects and support to local fisheries and tourism. An expert indicated that where marine protected areas have been

designated for coral reefs, some improvement has been seen in fish biomass and food web structure, but restoration has taken 10–15 years.

243. A Party asked for confirmation that **stringent mitigation pathways have considerable co-benefits for biodiversity** conservation or are essential to prevent biodiversity and ecosystem loss. She also noted that the **expected primary forest loss** in the RCP scenarios, which is very similar in all of them, does not take into account the climate change impacts on forests. She asked if these detrimental effects had been taken into account, the impacts of forest loss would be higher in RCP scenarios that do not keep temperature increase to low levels. An expert agreed that the greater the change in climate, the greater the threats to biodiversity. While recognizing that actions taken to address climate change action have clear biodiversity co-benefits, he warned that such action can also impact on biodiversity conservation. He called for attention to be paid to land-use change and emissions from the industry and energy sectors, as well as to the carbon stored in ecosystems beyond forests, including in the agricultural sector. He stressed the need for **building an incentive framework** that includes considerations of emissions from land-use change. He explained that in the **RCP2.6 scenario, the impacts from climate change on biodiversity are much reduced, but it implies significant land-use changes, which will be problematic for biodiversity**. He added that in order to reduce biodiversity loss, land-use change must be brought under control. He said that the scenarios presented indicate that it is **possible to achieve both the climate and biodiversity objectives** while ensuring food security, but this will not be an easy task and it will require adopting a very holistic approach. Another expert, noting some studies on geoengineering options that could locally raise the pH of oceans, stated that these options pose their own risks to biodiversity.

244. Another Party asked if **biodiversity loss projected for warming levels above 1.5 °C can be a damage multiplier of climate change impacts**, pointing to the coastal protection that coral reefs provide and that would be lost if they disappear (link through ecosystem services such as pollination, water purification and support for ecosystem based adaptation). An expert agreed that species extinction is a threat multiplier, underlining that the risk of extinction does rise from 1.5 °C to 2 °C of warming, but the details of how this will happen are not well known. While noting that evidence exists of the adverse effects of increased levels of warming on systems such as coral reefs or trees, he pointed to differences in impacts among regions and species. While recognizing that the details of the impacts of increased warming are not well known, he said that there is a high level of certainty regarding the fact that the risk to ecosystems and the services they perform rises with increased levels of warming.

245. A Party noted a paradox between the presentation by Mr. Leadley, who had said that the difference between 2 °C and 1.5 °C is really a matter of an increase in risk, while the SBSTA Chair had stated that what constitutes a tolerable risk may differ across regions, nations and sectors.

246. A Party noted that the Adaptation Committee reported that many bilateral organizations are receiving very few requests, indicating that the **utility of resources has been sub-optimal**. He asked how this opportunity could be better capitalized on. An expert explained that the fact that some bilateral institutions are not receiving many requests is not a challenge of optimal use, but **rather a challenge of institutional capacity**. He pointed to capacity constraints of some developing countries to make use of the existing opportunities. He indicated that in the future, bilateral agencies may support the global support programme if the countries feel more comfortable channelling their requests to the latter.

247. A Party asked how the **link between the CTCN and the NAP, TNA and nationally appropriate mitigation action (NAMA)** processes could be made more efficient, and requested more information on the LDC readiness programme within CTCN. An expert explained that to link the work of the CTCN to other processes, the CTCN will need to collaborate on the regional workshops planned for the TNA process, since the audience is the same, namely the NDEs. On the LDC capacity-building programme or 'incubator', he mentioned the caution of the CTCN to avoid overlapping with the capacity-building activities of other bodies. Noting that the Adaptation Fund is already carrying out some capacity-building and preparedness activities, he said the CTCN is looking at working in synergy with the Fund on this issue.

248. A Party asked about **non-climatic stressors** and possible success stories in addressing them that need to be taken into account when examining vulnerable ecosystems. An expert replied that while much research needs to be done on land ecosystems, evidence shows that land degradation is caused by human activities, but climate change exacerbates this trend, both in drylands and in non-dryland areas that are at risk. He called for addressing today's drylands and not those that are at risk. He pointed to the proposal from the UNCCD to restore 12 million

ha of degraded land annually, stressing the need for it to be part of the solution to addressing climate change. He added that INDCs are a viable option for including such a land component and suggested that the GCF consider how this could be supported. Another expert said that non-climatic factors that are important include **invasive species**, which are the cause of the greater number of extinctions, especially on islands. He pointed to the example of New Zealand, which successfully restricts the introduction of invasive species and controls them once they have been introduced. He also mentioned the case of pollution in Europe, where there are relatively high nitrogen deposition rates, and where substantial progress has been made by countries in setting ecologically significant nitrogen level limits. A third added that non-climate stressors, such as pollution or sedimentation, pose risks to corals, but it will take a long time and more studies to be able to differentiate their impacts from those of climate change. He noted however, that studies show that when there is intense temperature elevation, irrespective of water quality, mass coral bleaching may occur. He stated that it can be concluded with **reasonable certainty that thermal stress is the key driver**.

249. A Party welcomed the discussions on the links between climate change impacts on biodiversity and desertification and non-climate drivers and asked **how well we understand the importance of different drivers, and what action to address climate change has co-benefits for biodiversity conservation or to combat desertification**. He also asked if the impacts of ocean acidification could be tied to the level of CO_2 in the atmosphere. An expert explained that acting on non-climate stressors is frequently a 'no regret' solution, and that measures aimed at, for example, **reducing nitrogen pollution or pressure on overfished resources**, will increase the resilience of ecosystems to climate change. He noted the limited understanding of all the interactions among these stressors, as often models only take into account a small number of interactions. He pointed to some regional tipping points mentioned in the *Global Biodiversity Outlook*, warning that "synergistic interactions could lead to many bad surprises". Another expert indicated that there is no consensus within the scientific community on any 'safe level' of ocean acidification and related CO_2 concentration in the atmosphere, but some literature places this safe limit for corals at 350 ppm, a threshold that has already been passed. A third expert explained that a study he co-authored was not included in the assessment carried out by WGI as it was published after the IPCC cut-off dates.[39] He said that the temperature target does not cover all the aspects touched upon in Article 2 of the Convention, calling for **ocean acidification to be considered in a separate manner**. While recognizing that limiting temperature limits ocean acidification to some extent, and that more information is needed on the regional impacts of ocean acidification, he underlined that a separate target on ocean acidification may set a much lower amount of CO_2 concentration increases in the atmosphere. Yet another expert explained that scientific knowledge on the climate and non-climate drivers of desertification and land degradation is insufficient and underlined that land ecosystems are not sufficiently included in climate solutions.

250. A Party noted that over 50 per cent of land degradation stress in Africa is climate-related, and asked **how to assess the risk of land degradation arising from both climate and non-climate stressors** in the light of the ultimate objective of the UNFCCC. An expert referred to the very large portion of the population, in particular in Africa, which is affected by land degradation, pointing to AR5 findings projecting that drylands will become drier and that a larger portion of terrestrial area will become drylands.

251. In response to a question by a Party on the **scale of funding required to address land degradation and desertification**, noting that the UNCCD presentation indicated that drylands are vulnerable and that 40 per cent of total land mass is dryland, the expert questioned whether the MOI available will be adequate to address the current level of drylands, or that projected at 1.5 °C or 2 °C of warming.

252. Noting that LDCs have various priorities related to development and poverty eradication issues, a Party asked if the recommendation to **mainstream adaptation in development planning**, which has a cost implication, is appropriate for LDCs. An expert indicated that whether countries decide to mainstream adaptation or carry out stand-alone projects depends on the types of hazards and exposure they are facing. He added that in the case of LDCs, the consideration of reducing vulnerability comes as a complement to the second objective of NAPs, namely the integration of adaptation to climate change into other policies.

253. A Party asked if the CTCN had received any **request relating to adaptation technology in Africa**. An expert indicated that the CTCN had received three following requests from African countries: from Mali on

[39] Steinacher M, Joos F, Stocker TF. 2013. Allowable carbon emissions lowered by multiple climate targets, Nature. 499:197-201.

resilient rural communities; from Cote d'Ivoire on climate information systems for both adaptation and mitigation; and from Namibia on transformation of water harvesting systems. He added that the CTCN encourages the replication of its response activities in neighbouring countries.

254. A Party underscored the **importance of the intersections of the three Rio Conventions**, suggesting that while developing their NAPs, Parties should involve the resources under these three Conventions. She also pointed to the challenges faced by experts carrying out vulnerability or impact assessments in using the new climate scenarios produced by the IPCC and called for discussion on how to simplify the use of the IPCC scenarios for performing national impact, vulnerability and adaptation studies. An expert stated that the collaboration of the three Rio Conventions could materialize in the context of ecosystem-based adaptation in the next workplan of the Adaptation Committee, which is under development.

255. Noting that his country is in the process of declaring their entire exclusive economic zone as a marine protected area and a sanctuary to contribute to halting biodiversity loss, a Party asked the experts to elaborate on **the role of biodiversity in rendering key ecosystem services**, the possible impacts of losing such ecosystems, as projected above 1.5 °C of warming, and their importance for the livelihoods of traditional and indigenous communities. An expert underscored the critical importance of other ecosystems aside from corals in supporting fisheries, such as mangroves or sea grasses. He added that often the smaller the country, the more its population's livelihoods are dependent on these ecosystems. He indicated that 30 million people are directly dependent on systems supported by coral reefs.

256. A Party asked about the **adequacy of the technology management system under the UNFCCC**, in particular about who owns and requests the technologies, as well as about the role of market-based mechanisms in encouraging the transfer of technology. An expert explained that market-based mechanisms have shown they can mobilize technologies, pointing to the example of the CDM, which has mobilized technologies in a wide range of countries. He cautioned that this mobilization is linked to the level of incentives, which is currently not very high, and therefore does not provide the level of trust or long-term certainty needed by private actors to invest in the technologies. Another expert explained that the CTCN aims to provide technology-neutral advice to countries, who can then follow up with requests for more detailed advice on a particular provider or technology. He explained that further to a request from Parties, the CTCN is examining whether to establish a library of technologies and their providers. He cautioned that this may entail "a huge amount of work" because of the constantly changing landscape of climate technologies. He added, however, that one could look at technologies mentioned in Parties' national communications and share that information through other countries with an automated system.

E. Part 4: Regional and emerging information

1. Presentations by experts on regional information on the observed impacts of climate change

257. The ensuing discussion was guided by the following questions on theme 2 (subparagraphs (a–d) below) and theme 1 (subparagraphs (e–k) below) of the review:

(a) What are the most recent findings in relation to observed regional impacts?

(b) Are there regions in which some ecosystems cannot adapt naturally? Is their adaptation assisted or might it help to assist them, and by which means? What are the consequences for agriculture and development?

(c) What challenges does global warming pose to agricultural practices, policies and measures, from a regional perspective?

(d) What challenges does global warming pose to sustainable development from a regional perspective?

(e) How has progress towards the long-term global goal varied across regions?

(f) How do opportunities and barriers to adaptation and mitigation vary across regions?

(g) Which risks vary the most across regions? How do these risks vary at various levels of warming, notably with a warming of 1.5 °C and 2 °C relative to pre- industrial levels?

(h) How do risks for vulnerable ecosystems vary across regions at different levels of warming, notably with a warming of 1.5 °C and 2 °C relative to pre-industrial levels?

(i) How do regional food security risks vary at different levels of warming, notably with a warming of 1.5 °C and 2 °C relative to pre-industrial levels?

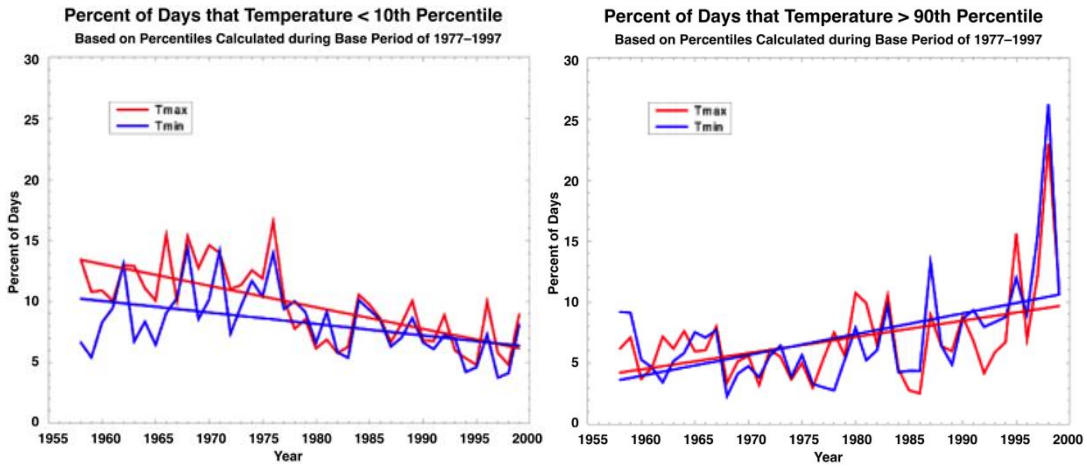
(j) How do observed impacts including those of sea level rise and extreme events vary across regions and at different levels of warming, notably with a warming of 1.5 °C and 2 °C relative to pre-industrial levels?

(k) From a regional perspective, what is the future of ecosystems, agriculture and sustainable development in the context of climate variability, climate change and uncertainty about future climate conditions?

258. Mr. Leonard Nurse, Chairman of the Board of Governors, Caribbean Community Climate Change Centre (CCCCC), presented a Caribbean perspective on observed impacts of climate change. In terms of temperature changes, he stated that the observed changes in the Caribbean reflect global trends. Over the period 1950–2000, there have been more warm days and nights, and fewer cold days and nights, a trend that is increasing (figure 94).

259. On **observed rainfall**, the mean annual rainfall on average between 1900 and 2000 has shown a constant decline by around 0.18 mm per year. In the southern Caribbean, over the period 1900–1980, there has been a contraction in the 'traditional' wet season, which typically lasts from June to October. There have been longer dry spells and increasing drought incidences since 1900, and there has been an increase in the number of heavy rainfall events in last 75 years. He pointed to the example of Saint Lucia, which suffered its worst drought in 40 years in 2009–2010, and was then hit by Hurricane Tomas in 2010, which produced 25 inches of rainfall in 24 hours in some areas.

Figure 94
Observed extreme temperature trends in the Caribbean



Source: Slide 2 of the presentation by Mr. Leonard Nurse (Caribbean Community Climate Change Centre), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_ccccc_sed4-2_feb9__1.pdf>. The figure shows for Caribbean since 1950 a growing trend in the number of warmest days and nights and a decreasing trend in the number of coldest days and nights.

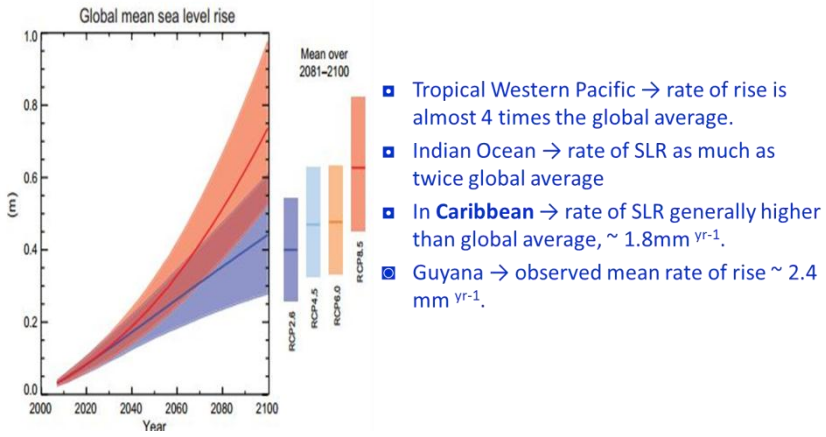
260. As indicated in the AR5 chapter on islands, he reported that the **rate of sea level rise around islands** is generally higher than the global average: in the tropical Western Pacific, the rate of sea level rise is almost four times the global average; in the Indian Ocean, the rate of rise is as much as twice the global average; in the Caribbean, the rate of rise is generally higher than global average, at approximately 1.8 mm per year; and in the case of Guyana, where there is land subsidence, the observed mean rate of rise is approximately 2.4 mm per year (figure 95).

261. He underlined that the impact of climate change on **freshwater resources** is "a tremendous concern to our region", pointing to declining mean annual rainfall, more frequent and longer dry spells, higher evaporation rates, salinity intrusion, and increasing present and future demand.

262. On **coral reefs**, he underscored that these high-value ecosystems are at high risk, that the casual link between **ocean warming and coral bleaching** is well established and that an increase in water temperature of less than one degree is enough for bleaching to take place. Mr. Nurse added that many studies show that Caribbean reefs will continue to be severely degraded in the coming decades, based on the response of corals to thermal stress, and that there is no field evidence that corals can evolve and adapt to unabated thermal stress, certainly not on decadal timescales. While recognizing that other, non-climate stressors are important, he said the thermal stress is "the key signal".

263. He reported on findings emerging from an EU-funded study that were released in December 2014, titled "FORCE – Future of Reefs in a Changing Environment", which compiled information on **aragonite saturation** levels. He explained that aragonite is a mineral form of calcium carbonate ($CaCO_3$) found in corals and some other marine organisms, and that the lower aragonite saturation state of water is beginning to affect the development of the skeletons of corals. According to the AR5 projections, as the oceans continue to acidify, the impacts of climate change on reefs are anticipated to become more evident and significant.

Figure 95
Observed sea level rise in Small Island Developing States regions in the twentieth century



Source: Slide 4 of the presentation by Mr. Leonard Nurse (Caribbean Community Climate Change Centre), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_ccccc_sed4-2_feb9__1.pdf>. The figure indicates that the rate of sea level rise in islands is generally higher than the global average.
Abbreviations: RCP = representative concentration pathway, SLR = sea level rise.

264. On **human health**, Mr. Nurse reported: a higher incidence of some vector-borne diseases since 1970, such as dengue fever, noting that some of the transmission factors are also climate sensitive; increased morbidity and mortality from hydro-meteorological events since 1950, particularly floods and storms; increased freshwater scarcity since 1960, with ensuing challenges for sanitation and hygiene; and a higher incidence of ciguatera fish poisoning in last four decades related to higher sea surface temperatures that provide favourable conditions for ciguatoxins.

265. On **tourism**, he highlighted direct and indirect effects from climate change: an increased risk to critical infrastructure such as air and seaports and accommodation; the amplification by sea level rise of ocean swell and storm surge elevations that lead to flooding, accelerated coastal erosion and land loss; and the loss of climate-sensitive attractions, in particular corals. He stressed that scuba diving "is not a trivial industry" and that revenues from scuba diving alone are significant in various Caribbean countries. For example, Bonaire earns over USD 50 million per year from recreational diver fees, and Belize earned USD 150–196 million from coral reef and mangrove-related recreation in 2007.

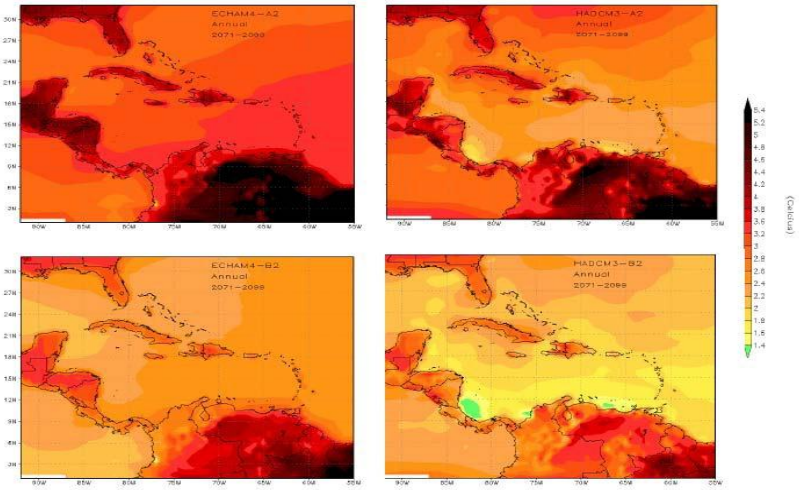
266. He presented some **downscaled projections for the region**, stressing that they are trending in the same direction as the observations, including: a projected 1–4 °C warming relative to 1960–1990 mean temperature by the end of the century; a projected 25–30 per cent decrease in rainfall before the end of the century; and a drying trend between -25 and -30 per cent by the end of the century, which far exceeds natural variability (figure 96).

267. Mr. Nurse then described the **Caribbean contribution to the achievement of the long-term global goal**. The Heads of State of the Caribbean Community and Common Market (CARICOM) mandated the CCCCC to develop a "Regional Framework for Achieving Development Resilient to Climate Change", which was approved in July 2009, and an "Implementation Plan". He said the Framework and Plan focus on key strategic elements, including economic trends and challenges, social sector trends and challenges, technology trends and challenges and energy for sustainable development. Mr. Nurse then focused on the energy pillar of the Framework. He reported that the Caribbean Community Energy Policy was adopted in 2013 and aims to transform the energy sector to provide clean energy. In January 2015, the Caribbean Energy Security Summit was co-hosted by the United States Department of State, the Council of the Americas and the Atlantic Council. The event brought together 26 countries, including all CARICOM States, who committed to "clean sustainable energy for all", and saw a pledge of cooperation from the United States Overseas Private Investment Corporation that proposed a clean energy programme in the Caribbean, including USD 43 million for a 34 MW wind energy project in Jamaica.

268. He also mentioned SIDS DOCK, an initiative developed by CCCCC and the South Pacific Regional Environment Programme (SPREP), which aims to: increase energy efficiency by 25 per cent compared with 2005 levels; generate a minimum of 50 per cent of electric power from renewable sources by 2033; and achieve a 20–30 per cent decrease in the use of conventional transportation fuel in SIDS by 2033. The partnership was established by a memorandum of understanding among the Alliance of Small Island States (AOSIS), the United Nations Development Programme, the World Bank and the Government of Denmark, and launched in December 2010 in Cancun, Mexico, with a USD 14. 5 million grant from the Government of Denmark.

Figure 96

Projected 1–4 °C warming by the end of the century (relative to 1960–1990 mean)



Source: Slide 11 of the presentation by Mr. Leonard Nurse (Caribbean Community Climate Change Centre), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/1_ccccc_sed4-2_feb9__1.pdf Juan Hoffmaister>. The figure shows the projections for mean temperature in the Caribbean for an A2 scenario (upper panels) and B2 scenario (bottom panels) using ECHAM4 (left-hand side panels) and HADCM4 (right-hand side panels).

269. He stated that these programmes are bearing fruit, citing the successful example of the Wigton Wind Farm in Jamaica. He also mentioned: the deployment of renewable energy and energy efficiency in the public sector in Jamaica; the Sustainable Energy for the Eastern Caribbean project in Antigua and Barbuda, Grenada, and Saint Vincent and the Grenadines; and a sustainable energy programme in Guyana.

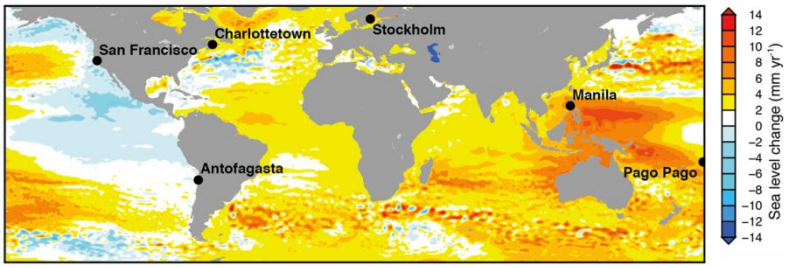
270. In concluding, Mr. Nurse emphasized that: climate change will continue to exacerbate existing challenges, as well as trigger new ones; **Caribbean countries believe that there is adequate, credible evidence to justify the pursuit of a long-term goal that limits global warming to 2 °C relative to pre-industrial levels**; delays in 'aggressive' mitigation will frustrate achievement of the long-term global goal and impose further limits on adaptation; and the Caribbean region has demonstrated a clear commitment to achievement of the long-term global goal.

271. Ms. Diane McFadzien, Climate Change Advisor, SPREP, presented views from the Pacific. She underlined that in the Pacific region, the islands are very spread out and some have small populations, elements that have a direct relation with the people's adaptive capacity. She described some observed impacts of climate change in the Pacific region, underlining that capacity to document or research these impacts is limited in the region. She said observed impacts are in line with the findings of the AR5.

272. On **temperature rise**, she noted: a persistent regional warming trend since 1961 (0.18 °C annual), with the warmest years on record in the last two decades; an increase of more than three-fold in the frequency of warm days and nights; an increase in rare extremes from 20 days a year to 45–80 days a year; and an increase in sea surface temperatures across the Pacific. On **sea level rise**, she indicated that the observed rate of sea level rise in the western Pacific is three times above the global average for 1993–2012. While recognizing that this may mainly be attributed to natural variability, she stated that it shows the high regional vulnerability to sea level rise, and underlined that projections of future regional sea-level rise are above global levels (figure 97).

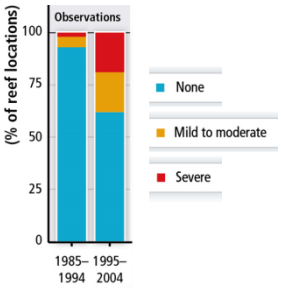
273. On observed impacts on coral reefs, she mentioned: an increase in coral bleaching re-occurrence and severity; a rapid decline in the abundance of reef building corals of 1–2 per cent per year for 1968–2004; and loss of ecosystems services and impacts on the GDP of countries in the region (see figure 98). Ms. McFadzien added that **saltwater intrusion and inundation** is also a concern, especially for atolls, with observed occurrences of salinization of limited freshwater resources, increased risks to agricultural production and food security, and negative health effects. On **health**, she pointed to: increased incidences of vector-borne disease, including malaria and dengue, especially endemic dengue in Samoa, Tonga and Kiribati; health impacts of changes to water availability, including cholera outbreaks after extreme events; and increased outbreaks of ciguatera fish poisoning linked to temperature increases.

Figure 97
Observed sea level rise from 1993–2012



Source: Slide 4 of the presentation by Ms. Diane McFadzien (South Pacific Regional Environment Programme), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2_sprep_sed4-2_feb9.pdf>. The figure shows a map of rates of change in sea surface height (geocentric sea level) for the period 1993–2012 from satellite altimetry (see Intergovernmental Panel on Climate Change Fifth Assessment Report, Working Group I, Frequently Asked Questions 13.1, figure 1).

Figure 98
Observed impacts on Pacific coral reefs



Source: Slide 5 of the presentation by Ms. Diane McFadzien (South Pacific Regional Environment Programme), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/2_sprep_sed4-2_feb9.pdf >. The figure shows the increase in impact on coral reefs in the Pacific from the period 1985–1994 to the period 1995–2004.

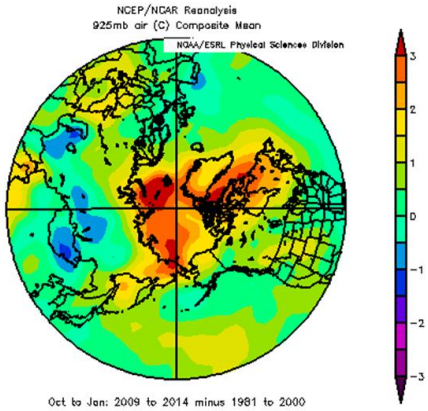
274. She underscored the **vulnerability to climatic extremes** of Pacific small islands, which rank high in relative exposure to tropical cyclones. She added that economic losses from tropical cyclones translate to losses in GDP of 15–25 per cent, hampering economic development. She outlined adaptation actions in the region, including: the strengthening of metrological services; capacity-building programmes, including the development of vulnerability and adaptation assessments, cost benefit analysis and ecosystem-based adaptation tools; the Pacific Adaptation to Climate Change project; and joint National Action Plans. She indicated that despite the very low level of emissions of countries in the region, various mitigation programmes are in place.

275. In concluding, she stressed that: the **Pacific has a substantial economic dependency on climate-sensitive sectors**, such as ecosystem services and tourism, with limited opportunities for economic diversification; **adaptation potential is limited for many of the observed impacts of climate change**; and

implementation of adaptation options, if available, **comes at very high costs** in relation to countries' national budgets.

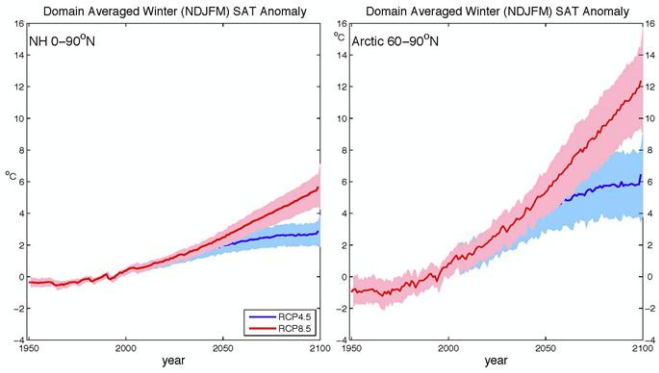
276. Mr. Lars-Otto Reiersen, Executive Secretary, Arctic Monitoring and Assessment Programme (AMAP) Secretariat, presented an Arctic perspective. He explained that the work of AMAP touches upon, inter alia: the status of the climate, climate feedbacks, the Greenland ice sheet, ocean acidification; sea ice snow cover, freshwater resources, permafrost and short lived climate forcers.

Figure 99
Arctic temperature amplification: 2-3 times changes in mid-latitudes



Source: Slide 4 of the presentation by Mr. Lars-Otto Reiersen (Arctic Monitoring and Assessment Programme), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/3_amap_sed4-2-feb9.pdf>. The figure shows that in the Artic the temperature increase is two to three times greater than that observed at mid-latitudes.

Figure 100
Arctic temperature



Source: Slide 5 of the presentation by Mr. Lars-Otto Reiersen (Arctic Monitoring and Assessment Programme), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/3_amap_sed4-2-feb9.pdf>. The figure shows that in the Artic the projected temperature increase for RCP4.5 and 8.5 is at least twice that projected for mid-latitudes.

Abbreviation: RCP = representative concentrations pathway, SAT = surface air temperature

277. On **temperature**, he explained that temperature amplification in the Arctic is three to four times greater than changes in mid-latitudes because of the **albedo effect**, i.e. the land and the ocean are absorbing more heat because of the melting of the snow and ice (figure 99). He presented new modelling graphs of the Arctic temperature based on scenario RCP4.5, which projects a 6 °C average temperature rise by 2100, and scenario RCP8.5, which projects a 12 °C rise by 2100 (figure 100).

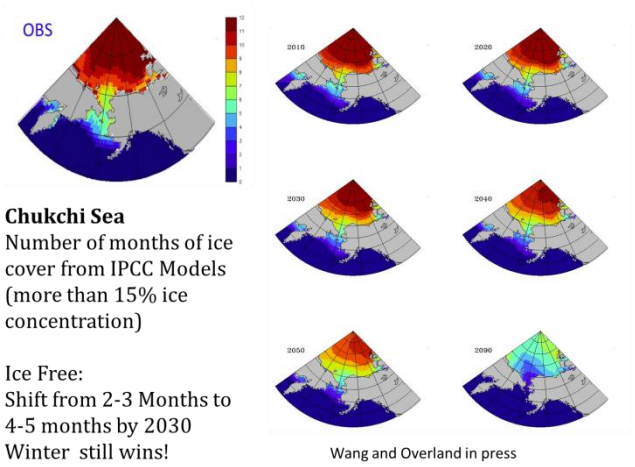
278. He underlined the importance of the volume of the sea ice, emphasizing that the ice has become younger and thinner since the end of the 1980s, with much of the older, thicker ice in the north of Alaska now melting away during the summer. He pointed to adverse impacts of the disappearance and thinning of the sea ice on polar bears, which are congregating in the north of Canada.

279. Mr. Reiersen then focused on **Pacific-Arctic Ocean heat storage**, pointing to an anomaly of 6–7 °C warmer waters in the straight between Alaska and Siberia. He underscored the importance of sea temperature, explaining that most of the **sea ice is melting from below**, owing to the increased sea water temperature. He presented IPCC models for the Chukchi Sea, showing a shift in ice-free months from 2–3 months per year to 4–5 months per year by 2030, and the projected total disappearance of sea ice by 2100 (figure 101).

280. He noted that the normal **Polar Vortex pattern of West to East flowing winds that traps cold air in the Arctic was broken down in December 2009** and in following years, allowing cold air to spill southwards, which partly explains recent extreme weather events in northern America and Europe.

281. On **snow cover**, he reported decreases of snow cover of up to 40 per cent in 2012 compared with 1971–2000 levels. Looking ahead, he showed projections of decreases in snow water equivalent, as well as in annual snow cover duration. On the **thawing of the permafrost**, he pointed to an estimated loss by 2100 of an average of 100 Gt of carbon from these areas (figure 102).

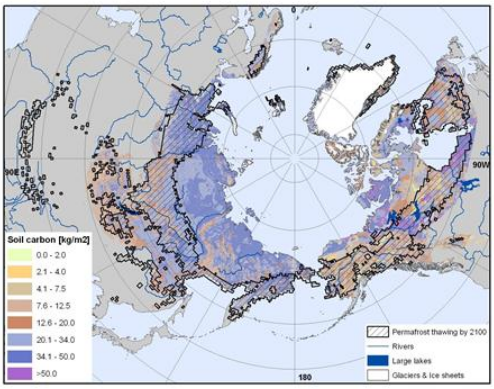
Figure 101
Sea ice cover in the Chukchi Sea



Source: Slide 8 of the presentation by Mr. Lars-Otto Reiersen (Arctic Monitoring and Assessment Programme), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/3_amap_sed4-2-feb9.pdf>. The figure shows the projected decrease in sea ice cover in the Chukchi Sea, over the period 2010–2090.
Abbreviation: IPCC = Intergovernmental Panel on Climate Change.

282. On the **run-off of water from Greenland**, he compared an Arctic climate assessment in 2011, which projected the water run-off from Greenland at 2 hundred Gt of water – the equivalent of the volume of approximately 1 m of water above the land mass of Australia – to the latest figures that double this amount, to approximately the equivalent of 2 m of water above the land mass of Australia, with a significant contribution to sea level rise. On **ocean acidification**, he pointed to the assessment published by AMAP in 2013, which indicated that: Arctic marine waters are experiencing widespread and rapid ocean acidification; the primary driver of ocean acidification is uptake of CO_2 emitted to the atmosphere by human activities; the Arctic Ocean is especially vulnerable to ocean acidification; and acidification is not uniform across the Arctic Ocean.

Figure 102
Reduction of permafrost by 2100



Source: Slide 13 of the presentation by Mr. Lars-Otto Reiersen (Arctic Monitoring and Assessment Programme), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/3_amap_sed4-2-feb9.pdf>. The figure shows the projected areas permafrost thawing by 2100 and the amounts of carbon currently trapped in those soils.

283. Noting that the Arctic is now opening up to mining, shipping and oil and gas activities, he said it faces new and emerging challenges, such as invasive species and health impacts affecting the people of the Arctic. He also pointed to the impacts of climate change and loss of sea ice on walruses and polar bears.

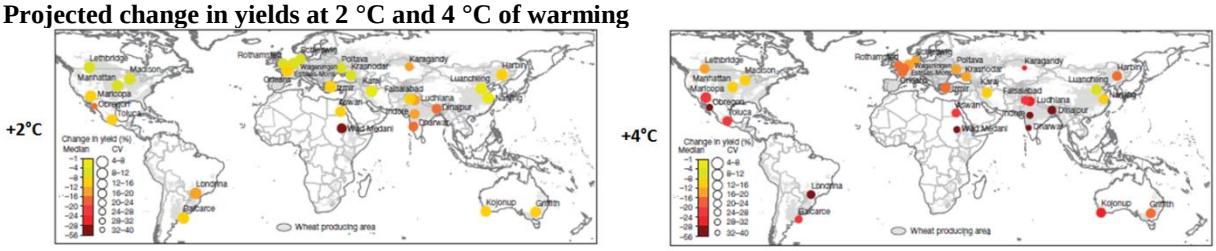
284. Ms. Sonja Vermeulen, Head of Research, CGIAR Research Program on Climate Change, Agriculture and Food Security, presented on agriculture and food security in a changing climate. She explained that she would

present some **key papers published after the IPCC cut-off dates**, which confirm the findings of the contribution of WGII to the AR5, in particular its chapter on agriculture and food systems.

285. She stated that **recent results**, for example from the Agricultural Model Intercomparison and Improvement Project (AgMIP)[40] **reconfirm AR5 findings** on **observed impacts** on crops, pasture and marine fisheries at global and regional levels. These findings indicated that from 1980 until 2008, negative climate impacts were observed on the yields of three of the four major crops (wheat, soy, maize), with consistent negative impacts across most regions for maize and wheat. She also recalled that the AR5 shows that by 2050, about 10 per cent of **projections** across all regions and all RCP scenarios expect a positive impact on crop yields, and 25 per cent of those studies project negative impacts, sometimes substantial. These **negative impacts are particularly concentrated in tropical areas**. She further underlined that research has focused on crops and mean impacts, with less research carried out on capacities and adaptation strategies, and on yield impacts of climate variability and extremes.

286. She then presented results from AgMIP, which aggregates 30 different models, with very high agreement among the agricultural models, relatively high agreement among downscaled climate models and fairly large differences among economic models that extrapolate impacts on food prices. She pointed to a paper emerging from AgMIP indicating that **wheat shows a six per cent yield loss for each degree of temperature rise**, equivalent to a quarter of the current global trade (figure 103).

Figure 103
Projected change in yields at 2 °C and 4 °C of warming



Source: Slide 4 of the presentation by Ms. Sonja Vermeulen (CGIAR), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/4_cgiar_sed4-2_feb9.pdf>. The figure shows projected changes in yields for 2 °C of warming (left panel) and 4 °C of warming (right panel) above pre-industrial levels. Wheat shows a 6 per cent yield loss for each degree Celsius rise, equivalent to
42 Mt or a quarter of global trade.

287. On **cash crops**, Ms. Vermeulen said they also face major impacts and shifts in growing areas, pointing to the example of regional changes in suitable growing areas for Arabica coffee in 2050, based on scenario RCP6.0. While recognizing that the 2013–2015 review is concerned with the difference between 1.5 °C and 2 °C of warming above pre-industrial levels, she stressed that **little agricultural research uses scenario RCP2.6,** and instead the higher RCP scenarios are used, particularly scenario RCP6.0 and scenario RCP8.5. In Indonesia, 84 per cent of current coffee-growing areas will no longer be at an economically viable level of production by 2050. While noting that other areas will open up, she pointed to arising adaptation issues, such as the low number of transport routes, unavailability of processing facilities, slow development of markets, etc. In Central America, she stressed that the need for coffee plantations to move up in altitude threatens areas that are protected for biodiversity and water management reasons.

288. Ms. Vermeulen then referred to a paper by Lobell and Tabaldi (2014) that finds that since **demand for food** will increase in the next 20 years, even small yield changes in that period are of major concern. She stressed that the likelihood of a 10 per cent yield loss in the next 20 years is: for wheat, less than 1 in 200 without climate change, and 1 in 20 with climate change; and for maize, less than 1 in 200 without climate change, and 1 in 10 with climate change. She drew attention to a recent paper that warns that **future food production is highly vulnerable to both climate change and air pollution**, with implications for global food security. The paper finds that **ozone** is playing an increasing role in wheat and rice production, and a lesser role in maize production.

[40] AgMIP is an international collaborative effort to assess the state of global agricultural modelling and to understand climate impacts on the agricultural sector.

289. On the impact of climate change on **livestock and marine fisheries**, she noted that less research is carried out in this field, and that yield outcomes for livestock depend on complex factors, particularly the availability of feed. She indicated that regional projections of rangeland and pasture yields are expected to be released during 2015. On marine fisheries, she indicated that with 2 °C of warming above current climatic conditions, yield losses are likely in Southeast Asia, Sri Lanka, Angola and Namibia, and yield gains are likely in Iceland and the southern coast of West Africa. She noted that the regions with high economic dependence on fisheries are likely to see a yield loss.

290. On **capacities to respond**, she referred to a study on empirical evidence from Brazil, Mexico and the United States of America that shows that both generic and specific capacities matter in determining food security outcomes. She stressed that both generic capacities, such as poverty levels in society and access to services, and specific capacities, such as climatic information to farmers or early warning systems, need to work in tandem. Underlining the importance of **water and water management capacities**, she cited the example of Afghanistan, where the impacts of extreme events on wheat yields can be decreased with irrigation, but will depend on the ability to maintain irrigation facilities.

291. Ms. Vermeulen mentioned that in Mexico, some breeds of heat-tolerant wheat have been able to overcome some of the heat impacts, but cautioned against the limits to these breeding interventions. She noted that "the real way in which farmers experience climate change" is in terms of **years of failure and increased risk to production**. She cited the example of Mozambique, where the fishermen have to go further off shore because of the declining fishing stocks, and are impacted by the storms that increase the risk of loss of life at sea, and that cause damages to their fishing gear, their houses and subsistence gardens. She called for substantially more work to be carried out on these risks and the impact of extreme events on farmers' livelihoods and their ability to 'bounce back' after major shocks.

292. She also referred to insufficient knowledge on the impacts of climate change on pests and disease, welcoming a call from the SBSTA to make submissions on that issue in March 2015.

2. General discussions

293. The ensuing discussion was guided by the following questions on theme 2 (subparagraphs (a–f) below) and theme 1 (subparagraphs (g–k) below) of the review:

(a) What are the most recent findings in relation to observed regional impacts?

(b) Are there regions in which some ecosystems cannot adapt naturally? Is their adaptation assisted or might it help to assist them, and by which means? What are the consequences for agriculture and development?

(c) What challenges does global warming pose to agricultural practices, policies and measures, from a regional perspective?

(d) What challenges does global warming pose to sustainable development from a regional perspective?

(e) How has progress towards the long-term global goal varied across regions?

(f) How do opportunities and barriers to adaptation and mitigation vary across regions?

(g) Which risks vary the most across regions? How do these risks vary at various levels of warming, notably with a warming of 1.5 °C and 2 °C relative to pre-industrial levels?

(h) How do risks for vulnerable ecosystems vary across regions at different levels of warming, notably with a warming of 1.5 °C and 2 °C relative to pre-industrial levels?

(i) How do regional food security risks vary at different levels of warming, notably with a warming of 1.5 °C and 2 °C relative to pre-industrial levels?

(j) How do observed impacts including those of sea level rise and extreme events vary across regions and at different levels of warming, notably with a warming of 1.5 °C and 2 °C relative to pre-industrial levels?

(k) What is the future of ecosystems, agriculture and sustainable development from a regional perspective, in the context of climate variability, climate change and uncertainty about future climate conditions?

294. A Party lamented the absence of a presentation on Africa, which has unique challenges. He stressed the importance of water security and suggested addressing **the mitigation co-benefits of adaptation action**, such as water desalination and mangroves. Stressing the uniqueness of the IPCC review process, he noted the gaps in regional information and expressed reservations with using emerging scientific information that is not as robust. He suggested deciding how to treat emerging data before hearing it, and further noted that the IPCC produces special reports, which deal with urgent matters and emerging information.

295. A Party asked how the indirect impacts of climate change on livelihoods can be assessed, in particular in LDCs and SIDS. An expert explained that **globally, very little food is traded**, particularly staple crops, with only 16 per cent of cereals being traded globally. She therefore underscored the importance of local food systems, stressing the need for national and subnational projections. On vulnerabilities in these communities, she said there are some well-established techniques for their assessment, pointing to work done by the International Livestock Research Institute (ILRI), which carries out assessments to identify hotspots of vulnerability to climate change. She further **stressed the importance of building small holders' own capacities**.

296. Further to a request for clarification by a Party on the annual rainfall figures presented for the Caribbean, an expert stated that the decline in annual rainfall in the Caribbean varies greatly spatially from 25 to100 inches depending on closeness to the coast, aerography and other factors. He explained that the figures presented are average declines reported by the reporting stations, mainly at airports and farming stations.

297. A Party asked what the available **options for economic diversification in SIDS** are, given the impacts of climate change on various economic sectors, in particular agriculture, tourism and fishing. An expert explained that for **tourism**, the **options for economic diversification are limited**, noting that tourism in the Pacific is driven by foreign ownership and that diversification will most likely imply moving to more appealing locations. She added that the local population will be most hit, with employment losses, in particular as coral reefs and ecosystems that attract tourism are becoming eroded. She pointed to some examples of attempts to develop cultural tourism in order to move away from coral-dependent activities.

298. A Party asked about the **links between adaptation and mitigation in the regions discussed**. An expert explained that mitigation actions in the Caribbean have been implemented as part of a larger package of adaptation and mitigation efforts aimed at achieving sustainable development. He outlined some co-benefits of mitigation action, including **savings of foreign exchange**, **lower energy rates provided to consumers**, **health benefits** and **increased energy access**. He also pointed to some co-benefits of solar dryers used by farmers, noting that their use is being scaled up. Another expert pointed to the example of the **alternate wetting and drying irrigation technique in rice cultures** carried out in China, India, Japan, Philippines and Viet Nam, which leads to adaptation and food security gains via reduced input costs for farmers, as well as mitigation benefits because of the avoided CH_4 emissions of about 48 per cent.

299. A Party asked which adaptation strategies would be appropriate in the Himalayas and if there are plans to address the information gaps identified in the AR5. An expert drew attention to similarities between the Alpine areas and the Arctic, in particular the melting of glaciers. He said some of the work carried out in the **Arctic on adaptation options** could be applied in the Himalayas. He added that very little data is available on adaptation needs in the Arctic and looked forward to cooperation with other regions facing similar challenges. Another expert indicated that research findings published after the **IPCC cut-off dates** confirm the AR5 findings, in particular in relation to the **retreat of glaciers, ocean heat uptake** with regional impacts and **statistics on extreme events**.

300. A Party asked if a **regional adaptation plan exists in the Caribbean region**, and if a financial assessment of the **adaptation and mitigation needs of the region** has been carried out. An expert explained that the Regional Framework for Achieving Development Resilient to Climate Change adopted by the Caribbean Heads of State includes an **adaptation** component. On financial needs, he referred to work in the region on projections, primarily on sea level rise. Some of the modelling for a 1 m **sea level rise** for the Bahamas, Belize, Guyana and Suriname combined is projected to amount to annual **GDP losses of USD 1.2 billion**; the loss of at least 16 multimillion dollar tourism resorts; USD 4 billion in infrastructure costs, with significant transportation losses at airports; and USD 5 billion for relocation loss. Another expert referred to table 16.3 in chapter 16 of the contribution of WGII to the AR5, which identifies **adaptation opportunities, constraints and limits**, and to section 16.6, which addresses mitigation and adaptation interactions.

301. A Party asked about the **economic quantification of the projected losses in the agricultural sector**. An expert said that an increasing number of studies have quantified losses incurred as a consequence of climate change, for example the projection of a loss of 42 million tons of wheat or a quarter of global trade for each degree of warming. She also pointed to a historical study on climate change impacts on wheat, maize, rice and soy between 1980 and 2008, which estimates the yield losses due to climate change, for example a 3.8 per cent global average loss, which is equivalent to 23 million tonnes or the total production of Mexico, and a 5.5 per cent yield loss for wheat, which is equivalent to the total production of France. The study also examines the impacts on food prices (e.g. 6.4 per cent increase in food commodity prices considering that carbon fertilizing of the crop has taken place or an 18.9 per cent increase without carbon fertilization). Another expert indicated that **increased yields are projected in the Arctic**, as some vegetables that could not be grown before will be produced, but stressed that this is a "**very minor positive effect**" of warming temperatures.

302. A Party asked what the **costs of the mitigation actions outlined in the presentation on the Caribbean** are, what the **costs of adaptation in all the vulnerable regions presented** are, and whether technologies are available to address mitigation and adaptation needs. An expert said that although there are some national-level studies related to costs of adaptation and mitigation, they are not comprehensive and tend to focus on particular sectors. In a study by the United Nations Economic Commission for Latin America and the Caribbean on the economics of climate change, the figures are highly variable from country to country and a gross figure is not available at this time.

303. A Party pointed to a **gap in information from Latin America**, while recognizing that representatives from that region had failed to suggest institutions that could have delivered a presentation at the meeting. He suggested that the SED 4 report mention that according to the AR5, **observed temperature over the last 20 years has increased by an average of 0.5 °C per decade, and that the rate of warming in Central America is twice the global mean**. He also referred to a recent report of the Inter-American Development Bank (IDB) titled "Climate Change at the IDB: Building Resilience and Reducing Emissions", which indicates that GHG emissions of the 26 countries of the region decreased after 2005, largely because emissions from land-use change and forestry fell by 44 per cent between 1990 and 2011, mainly as a consequence of reduced deforestation in the Brazilian Amazon. The report also finds that Latin America and the Caribbean's electricity mix is cleaner than those in other world regions.

304. Noting that the presentations confirmed the findings of the IPCC and the need for the global goal, a Party asked if changes **in urban, spatial and development planning** had been observed in vulnerable areas to address vulnerability and exposure to climate change risks. An expert underlined that issues related to **exposure** are critical, pointing to a number of initiatives in the Caribbean that aim to reduce exposure, such as the Caribbean Uniform Building Code (CUBiC) that contains provisions to reduce exposure to impacts from hurricanes and flooding. He also referred to training of country planning officers in climate change vulnerability analyses. The expert underscored the importance of governance in making adaptation more effective, citing a chapter dedicated to this issue in the Regional Framework for Achieving Development Resilient to Climate Change. He stated that insurance and reinsurance are "hugely important" in the Caribbean to lessen the risks posed by climate change. Noting the high costs of these measures, he added that they are part of a suite of adaptation approaches. Another expert described some changes in **infrastructure planning** due to climate change impacts in the Arctic, including the erosion of soft coastal areas due to loss of sea ice protecting the coast from waves, **driving populations in Alaska to migrate inland,** and thawing of permafrost affecting roads and buildings. He stated that a lesson learned from the events that will affect the North is that the average temperatures "are maybe not the most interesting", the **important indicators are the extremes**.

305. While recognizing that having a presentation of all the regions was not feasible, a Party suggested that the 2013–2015 review be informed by the volume on regional information of the contribution of WGII to the AR5. An expert described the strategy adopted by **WGI to address the regional aspects of climate change**. He said that for the first time, WGI took a process point of view to better understand the future impact on affected regions of climate process modes, such as El Niño or the Pacific oscillation, along with long-term trends. He indicated that the chapter also includes an atlas of 37 regional projections, available in digital form, which provides data for three time horizons and all four RCP scenarios, on temperature and precipitation anomalies. He specified that the atlas covers in detail the African and Mediterranean regions and provides data relevant to droughts and water shortages. The expert also mentioned the Coordinated Regional Climate Downscaling Experiment (CORDEX) that covers 14 regions, with regional scale models, providing 'fine-grain' information

and the emerging Coupled Model Intercomparison Project Phase 6 (CMIP6) effort. He underlined that in the near future, the WGII community will have increased access to a lot of new physically based information relevant to regional impacts and risk studies. Another expert added that the contribution of WGII to the AR5 includes a full volume on regions, with nine regional chapters, including one on oceans. He pointed to chapter 21 of that volume, which is an introduction that explains the caveats on the regional aspects. He added that the information presented: is mainly from WGII, with an introduction outlining WGI information; addresses non-climatic stressors, such as land-use changes and socio-economic conditions; and includes some aspects coming from WGIII.

306. Mr. Clifford Polycarp (GCF) explained that the GCF is "now shifting gears to move to full scale operations". He said that in 2014, the Fund focused on mobilizing resources and reached a target of USD 10 billion. In order to **start committing resources**, he stressed the need for: each country to designate a **national focal point** responsible for all GCF operations and engagement in that country – approximately 50 countries still have to designate one; **institutions to be accredited to the GCF**, according to its standards, which are differentiated according to a 'fit for purpose' accreditation criteria, with the first batch of accreditation expected at the Fund's Board meeting in March 2015; and **proposals for projects and programmes from the accredited institutions**, which should be in line with the country's priorities, support at least one of the Fund's eight strategic results, and meet the Fund's six funding and investment criteria. He added that the Fund's eight strategic results cover all sectors, and that overtime, the GCF will need to: maintain a 50-50 balance between adaptation and mitigation; maintain a regional balance; and allocate 50 per cent of its adaptation funding to SIDS, LDCs and African countries.

307. He indicated that over the coming months, the GCF will develop more detailed guidelines on these requirements and processes. For several countries, capacities will need to be built or strengthened to enable them to access the Fund's resources and use them effectively. Mr. Polycarp explained that the Fund can already start to provide **readiness support to strengthen the designated national authorities**. He reported that the Fund is in 'active dialogue' with approximately 50 countries on their possible proposals, with about a dozen concrete proposals being developed.

308. In concluding, he underscored the importance for designated national authorities to be in place in all developing countries, a diverse range of public and private entities to be accredited, and a handful of projects to be approved by the GCF Board before the end of 2015.

309. A Party asked if a global warming of **2 °C or 1.5 °C** above pre-industrial levels would imply the passing of some **thresholds in the Arctic**. An expert explained that 2 °C warming on the global level would imply a temperature **change of twice that amount in the Arctic**. He underscored the importance of **the speed of change**, which affects the ability of animals to adapt, in particular those linked to the ice. He added that new species are already appearing in the Arctic region at current levels of warming. In the oceans, new species are coming in, such as mackerel and will "fight" with traditional species of the Arctic.

310. A Party asked if research had been carried out on: the impacts of climate change on **crops like sorghum, beans** and others that contribute significantly to the GDP of African countries; the impact of parasites on these crops and the impact on livestock; and the associated adaptation costs. An expert indicated that substantial impact studies on major crops such as sorghum, beans, yams and cassava, have been carried out in Africa. She added that research on livestock in general, as well as on pests and disease, is a weak area.

311. A Party pointed to the **limits to adaptation**, in particular in relation to the risks posed by **sea level rise and climate extremes to ocean ecosystems**, and asked how these risks amplify with the ongoing warming, and how they threaten the ecosystem goods and services provided. An expert stated that the services provided by marine ecosystems can be either marketed or non-marketed. He cited the example of coral reefs that provide sand for beaches and absorb, reflect and dissipate wave energy from high energy events. If they are lost, countries would have to replace them by coastal engineering protection measures that are extremely costly. These costs could be a barrier for many island States. He also mentioned the services provided by mangroves, including habitat for fish and filtering of land-based contaminants. He explained that putting a dollar value on fisheries is much easier than other ecosystem services that are equally critical, and that only indicative values are available. The expert also referred to the cultural importance of ocean and coastal areas, noting that in some Pacific islands some coastal cemeteries have been lost.

312. A Party noted that while the higher emissions RCP scenarios are used in agricultural studies, they make projections to 2050. Given that the warming level for all these scenarios is similar in the near-term he asked if these results can help illustrate the differences between 1.5 °C and 2 °C of warming. An expert agreed that in broad terms, in the higher emission scenarios, the global temperature can be expected to be approximately 2 °C warmer in 2050. She also drew attention to the fact that the AR5 refers to a temperature increase of 2 °C as a tipping point in terms of impacts on agriculture, particular in temperate regions.

313. A Party asked for more information on the solutions to address the increasing pressures on freshwater supplies, in particular the challenges associated with precipitation changes and salt water intrusion. He asked if they had explored some solutions, such as desalination and the challenge it poses. He also asked if the CTCN is working in Africa or the Near East on this issue. An expert explained that a wide range of solutions to address freshwater scarcity had been implemented in the Pacific region, stressing that no "one size fits all". She referred to work on demand-side management, such as measures to address leakages, and supply side management. She also outlined challenges related to the development of rainwater harvesting, such as land tenure issues or the inadequacy of traditional roofs to collect water. She stated that desalination is "the least popular option" because of its high costs. Another expert added that although desalination has been seen as a panacea for coping with freshwater stress in small islands, some of the challenges associated with this solution include: management of the risks associated with the disposal of the brine; its negative impacts on marine ecosystems where there is poor disposal of the brine, for example too close to the shore; and its high energy intensity. However, he also mentioned a successful desalination project of the CCCCC in Saint Vincent and the Grenadines powered by photovoltaic energy, which produces a surplus of energy.

314. A Party asked if lessons could be learned from a study of 2014 on the unique situation of the corals living in the bays around Palau's Rock Islands, where coral reefs thrive despite acidic oceans. An expert said that it may be too early or too difficult to extrapolate from the findings of that "perplexing study" across other reefs, adding that the reefs in question have adapted to the increasing acidity of the water over a very long timeframe. In contrast, existing reefs will have to adapt over decades, to a much higher rate of acidification. He also said that it is not clear if those coral will survive in water at lower acidity. Another expert underlined that the variability of conditions affects the comparability of situations. He said that the reefs in the study may be able to survive in water with high acidity because of the absence of other pressures, or that the acidity of the waters may only be slowing the rate of their growth, which would impact their recovery between bleaching events. In the absence of bleaching those corals were not tested on how rapidly they could grow. He stressed that this local study requires further investigation.

315. A Party asked for more details on the **existing mitigation possibilities in the agricultural sector**, and if any **initiative exists to promote and share good practices in this field**. An expert explained that direct emissions from the **agricultural sector account for approximately 12–14 per cent of global emissions**, with livestock management, rice management and agricultural soils as major subsectors. She also stressed the role of agriculture as a driver of deforestation. She identified hotspots for mitigation opportunities, including **managing water levels in rice cultures**, which comes with economic benefits, or **changing feeding regimes and managing herd sizes in ruminants**. She underlined that the greatest mitigation potential is in relation to the **carbon stored in the soil**, but that technically, it is difficult to raise the level of carbon in the soil. On good practices, she explained that CGIAR is working on **climate-smart villages** where farmers and researchers test packages of interventions, such as water management techniques, weather-based insurance and the provision of weather services to farmers.

316. A Party asked which are the **GCF's priority areas in mitigation** to ensure that its resources will be channelled to those activities that have the highest impact, and how does its approach differ from that of the GEF. In particular, she asked to what extent the decarbonization of the energy and industrial sectors is reflected in the GCF priorities. An expert explained that the GCF results framework includes four areas on mitigation: energy, transportation, forest and land use, and buildings and cities. While stressing that the GCF will have to support emission reduction activities in all four areas, he stated that considering the significance of the energy sector, many demands are expected from it.

317. A Party asked how much of the USD 10 billion pledged to the GCF has been deposited. He also referred to the difficulties faced by some national financial entities in disclosing fiduciary information, which may be requested in order to be accredited with the GCF. He then asked about how the GCF was planning on mobilizing adaptation funding, and how the 50 per cent of resources to be allocated to adaptation was going to be carried

out, either through a ceiling over the whole portfolio of the GCF or on a regional basis. An expert explained that the process of realizing the pledges into agreements is underway, and that the GCF aims to have 50 per cent of the pledged amount deposited by the end of April 2015. On **fiduciary requirements** for entities seeking accreditation with the GCF, he said the Fund uses an online application system, assuring that all the confidential information disclosed will be treated as such. On the **adaptation window**, he indicated that there is no decision from the COP or the GCF Board on this issue, and that the adaptation projects and programmes could come from any source. On the **distribution of projects**, he said the current targets are at the portfolio level, and that the Fund is to ensure regional balance among projects, but does not have any specific numerical target.

318. A Party asked about the status of the request by COP 20 to the GCF Board to accelerate the operationalization of the adaptation and mitigation windows, and to ensure adequate resources for capacity-building and technology development and transfer, as well as the status of the development of a monitoring and accountability framework for the GCF. An expert explained that underlying the Fund's results framework is a performance measurement framework that will be accompanied by indicators, including the number of people affected by the project. He added that work on the development of the performance measurement framework started in 2014 and is still ongoing.

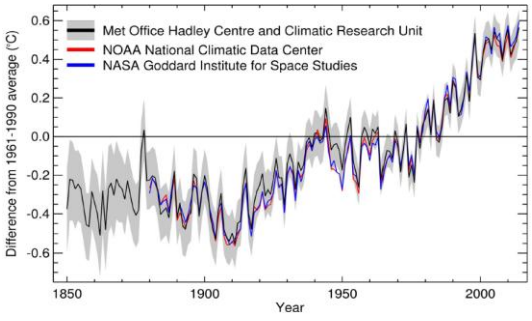
F. Part 4: Emerging information

1. Presentation by experts

319. Mr. Rajendra Pachauri, IPCC Chair, was unable to deliver his presentation as scheduled. A copy of his Power Point presentation is available on the 2013–2015 review page on the UNFCCC website.[41]

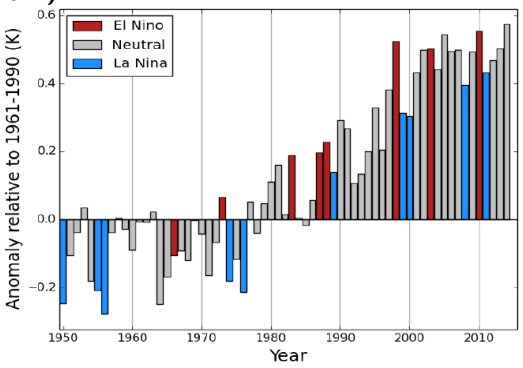
320. Mr. Deon Terblanche, Research Director, WMO, delivered a presentation on behalf of Mr. Jerry Lengoasa, WMO Deputy Secretary-General, on the current state of the climate and updated information published after the IPCC cut-off dates for literature to be considered for the AR5. His presentation addressed the latest evidence on the observed state of the global climate, knowledge of GHGs in the atmosphere and how to address knowledge gaps.

Figure 104
Global average temperature anomaly (1850–2014)



Source: Slide 3 of the presentation by Mr. Deon Terblanche (World Meteorological Organization), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/6_wmo_sed4-2_feb9.pdf>. The figure shows the increase in global average temperature since 1850, and that the 2000–2010 decade was the warmest on record.

Figure 105
Global average temperature anomaly (1950–2014)



Source: Slide 5 of the presentation by Mr. Deon Terblanche (World Meteorological Organization), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/6_wmo_sed4-2_feb9.pdf>. The figure shows that 2014 ranks as the warmest year on record, in particular in the absence of El Niño.

[41] See: <http://unfccc.int/7521.php>.

321. He described a graph showing the **global average temperature anomaly** for the period 1850–2014, stressing that, according to the calculation method used, 2014 was the warmest year on record. He underlined that not only was 2014 the warmest on record, but in addition, it was not an El Niño year (figure 105).

322. **On the oceans**, he indicated that averaged global sea surface temperature for the period January–December 2014 was estimated at 0.48 °C above the 1961–1990 long-term average, a record high value. The 2014 average of the ocean heat content estimated for the 700 m and 2000 m layers was higher than for any earlier year on record.

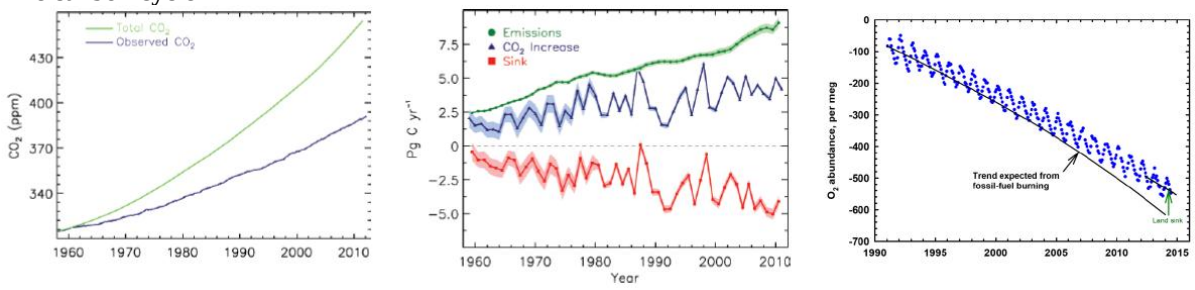
323. From the work of the World Climate Research Programme (WCRP), of which WMO is a co-sponsor, he cited an article that presents evidence suggesting that as the **Arctic continues to warm faster than elsewhere** in response to rising GHG concentrations, the frequency of extreme weather events, such as cold spells, stormy periods, heat waves and droughts, caused by persistent jet-stream patterns will increase. He underlined that what happens in the Arctic has implications "way beyond the Arctic" with impacts at mid-latitudes and beyond.

324. **On GHG concentrations in the atmosphere**, he referred to the WMO Global Atmosphere Watch (GAW) programme, which aims to provide high-quality observations of the chemical composition of the atmosphere and improve the understanding of the increasing influence of human activity on the global atmosphere. He stated that: atmospheric CO_2 continues to increase every year, a trend largely driven by fossil fuel emissions; atmospheric CO_2 levels were above 400 ppm at the Mauna Loa observatory for three months beginning in April 2014 for the first time; and the growth rate of CO_2 concentrations varies greatly from year to year with the global growth rate between 2012 and 2013 the largest since the current global record started in the 1980s. The growth rate has been increasing on a decadal basis, as inter-annual variability is largely driven by the sinks of the Earth system (ocean and biosphere).

325. On the **complexity of the carbon cycle**, he presented three graphs showing the expected increase in atmospheric CO_2 based on the total emissions compared with the observed values in the atmosphere (figure 106, left-hand side panel); anthropogenic emissions, sinks with strong inter-annual variability, and the resultant increase in atmospheric CO_2 (figure 106, middle panel); and observed slow decrease in oxygen abundance in the atmosphere due to the burning of fossil fuels, which can be used to discriminate between ocean and terrestrial biosphere sinks (figure 106, right-hand side panel). He explained that improving observations will enable better quantification of the sources and sinks, stressing that knowledge of terrestrial and ocean sinks is essential for better understanding the anthropogenic contribution.

326. On **ocean acidification**, he also reported an upward trend in ocean acidity at a few sites, despite the lack of a global representative figure. He underscored the need to standardize the measurements in the atmosphere and the oceans with the aim of achieving common calibration standards.

Figure 106
The carbon cycle



Source: Slide 10 of the presentation by Mr. Deon Terblanche (World Meteorological Organization), available at <http://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/6_wmo_sed4-2_feb9.pdf>. The figure shows: the expected increase in atmospheric CO_2 based on the total emissions compared with the observed values in the atmosphere (left-hand side panel); anthropogenic emissions, sinks and the resultant increase in atmospheric CO_2 (middle panel); and the observed changes in oxygen abundance in the atmosphere due to the burning of fossil fuels (right-hand side panel).

327. He stated that society is attempting to advance efforts to reduce CO_2 emissions and will likely do so even more in the future; mitigation efforts will vary by country, region and emission sector, and be diverse in their approach; **the complexity of the carbon cycle is such that tracking the adequacy of aggregate measures to achieve the long-term global goal will require considerable monitoring system enhancements**; and emission

reduction approaches require independent, scientific monitoring to support verification and policy decisions. He then outlined gaps in the current integrated observing system, including: insufficient density of observations over land, the sea and in the free atmosphere; insufficient measurements of isotopes and co-emitted gases for source attribution; incompatible observations on different scales and in different media (e.g. atmospheric observations versus partial pressure CO_2 observations); and insufficient complexity and performance of transport models on global, regional and local scales. He stressed the need for a comprehensive GHG information system that would include atmospheric, oceanic and land measurements. This would imply that WMO/GAW and the Global Climate Observing System, which oversee most of the long-term atmospheric measurements, and other organizations, which oversee the oceanic and land measurements, work together to that end.

328. In concluding, he underscored the need for: the **development of the observing system in all domains**; investment in observation in the atmospheric domain due to its role in mixing, transport and radiative forcing in order to obtain maximum benefits in the short term; the development of the modelling tools to deliver products on the temporal and spatial scales relevant to decision-making; collaboration between the 'spheres', i.e. atmosphere, oceans and biosphere; and inter-agency coordination.

2. General discussion

329. A Party underscored that global measurements of CO_2 in the atmosphere not only indicate an upward trend, but also an **increasingly upward trend**. He stated that "if one message comes out of the review process, it has to be that **we are not on track to deliver 2 °C**". An expert explained that about half of the total GHG emissions have been absorbed by the oceans and the terrestrial biosphere, but pointed to the great inter-annual variability of the sinks, as well as the great amount of uncertainty in terms of how the oceans and terrestrial biosphere will react in future and the risk that this entails.

330. A Party asked for views on findings published after the IPCC cut-off dates on the **instability of the east Antarctica ice sheet**, and that its irreversible retreat may be triggered at low levels of warming, leading to higher projections in sea level rise. An expert indicated that WGI placed a large emphasis on looking at new comprehensive assessments of sea level rise, as reflected in the scoping exercise that proposed dedicating a chapter of the WGI report to this issue. He said that the chapter on sea level rise enabled the group to collect the expertise in the scientific community in a comprehensive manner. He stressed that sea level rise estimates and projections widely varied in the scientific literature assessed, with various model types used to project sea level rise, some fully based on physical processes, others being semi-empirical models. The author team was able to provide projections for the end of the twenty-first century for the first time including all relevant components: the thermal expansion of the water due to warming; the melting of the large ice sheets, Greenland and Antarctica; as well as the melting of glaciers and storage use changes. Recognizing that science has progressed since the IPCC cut-off dates, he said the new results published would not lead to a full revision of the IPCC assessment, but rather add interesting details that strengthen the possibilities outlined. He added that if instabilities are triggered in ice sheets, this could lead to a sea level rise of up to 7 m by 2300 over a millennium if the Greenland ice sheet is sent on a pathway of total melt down. He also stressed that the AR4 thresholds were revised downwards in the AR5, and that the IPCC gave low confidence to the possibility of a large amount of the Greenland ice sheet melting at 1 °C of warming above pre-industrial levels. He underscored that the new emerging science is limited to observation, highlighting the importance of understanding ocean warming and its interaction with the ice sheets. He concluded that the possibility of potentially higher sea level rise and the new scientific findings will have to be assessed in the next IPCC cycle. Another expert added that satellite observations are becoming increasingly important in the field of sea level rise, calling on satellite agencies to invest in the capabilities to monitor ice sheets and sea levels. A third expert indicated that AMAP is in the process of updating the latest assessments from 2011, which will be presented in March 2017, supporting the need to improve the network for observations in the Arctic, as well as the models which enhance our understanding of feedbacks.

331. A Party **cautioned against using non-IPCC information**. Mr. Fischlin underlined that Parties may ignore information that has not been assessed rigorously enough, but said that they may also take it into account in a risk-management context. Another Party underlined the importance of looking at the long-term trend, noting that while the IPCC is "the gold standard", the review process should be open to other sources that can help increase our understanding of climate change.

332. A Party asked about the **uncertainties related to the findings that 2014 was the warmest on record**. An expert explained that in the past decade, we have had a number a very warm years (2014 was the warmest but was very close to 2010 and 2005). He stressed the importance of the general trend and comparing on a decadal basis, which clearly indicates an upward trend. Mr. Fischlin asked if the new findings on 2014 change the trends published by WGI in the summary for policymakers in its contribution to the AR5. An expert indicated that the observations for 2014 had not been assessed by the IPCC yet, underlining the distinction among observation, information and assessment. He said that establishing the value of global temperature change is difficult, stressing that large areas of the globe are unobserved, and where information has to be interpolated. While recognizing that there is uncertainty, he stated that there is high probability that 2014 was indeed the warmest year on record. He underscored the importance of trends over individual years, emphasizing that the WGI approach is decadal averages, and that "we are looking at a series of years that are, altogether, the hottest over the past 60 years". He added that the fact that El Niño had no part in the warming, and that nonetheless 2014 was the warmest on record, is important to note.

333. A Party asked about the **relationship between temperature and CO_2 concentrations**, which produces a linear relationship. Noting that there are thresholds that, if passed, will cause severe irreversible impacts, he asked if the review's focus on the linear relationship makes us disregard some other key severe risks and threats. An expert said there is no simple linear relationship between actual or current CO_2 concentration in the atmosphere and the current global mean temperature. This near-linear relationship does exist between cumulative CO_2 emissions and projected temperature rise in the twenty-first century. He pointed to figure 10 of the summary for policymakers in the AR5 SYR, which brings together the unique assessment of risks in five categories, associated with information from WGIII on required emission reductions.

G. Closing

334. Mr. Zou Ji outlined some reflections on the work carried out by the SED and its role within the science–policy interface. He reminded participants that the SED had held five meetings since its inception, in conjunction with meetings of the subsidiary bodies. He outlined a few common aspects of all SED meetings, and commented on the dialogue that had taken place over the four sessions of the SED. He stressed that all meetings of the SED shared some common aspects, both procedural and of substance, which he said illustrate the transparent, participatory and balanced way the meetings were organized and carried out, as well as the robustness of the science presented.

335. First of all, all meetings of the SED were open to all Parties and observers. Second, their organization was always based on submissions by Parties, and the SED co-facilitators published an information note ahead of each meeting to ensure the transparency of the organization of the meetings. Third, SED meetings were organized as a fact-finding exchange of views between experts and Parties. He indicated that a total of 60 presentations were made by 73 experts. The experts presented findings from the AR5, relevant reports and work of United Nations organizations and others, as well as bodies under the Convention, highlighting their relevance to the 2013–2015 review. While noting that a majority of IPCC experts were invited to present at SED meetings (33 of the 73 presentations were made by IPCC experts), he expressed his belief that this reflected the fact that the AR5 is "the most robust and authoritative assessment of climate science to date", and that decision 1/CP.16 specifically mandated that the review be informed by IPCC sources.

336. Mr. Zou Ji added that a significant number of non-IPCC experts were also invited, and that the geographical, cultural and gender balance among invited experts was always respected. He stressed that non-IPCC experts presented, in a balanced manner, information sources from United Nations agencies and other international organizations, as well as observed regional impacts of climate change.

337. He then addressed the format and substance of the discussions. Mr. Zou Ji underlined that the presentations made at SED meetings were always followed by a moderated discussion that addressed guiding questions and questions from all participants. Furthermore, at all SED meetings, the amount of time allocated to discussions was significant, always exceeding that allocated to the presentations themselves. The meetings were all well attended, bringing together many government delegates and experts from all regions, as well as civil society representatives. He stressed that delegates engaged in a remarkably constructive, productive and rich manner in all discussions with experts, often asking follow-up questions that deepened the debate. He also underscored that at SED 3 and 4, experts presenting in one part also attended other parts of the session, allowing for linkages to be made among presentations, and the interrelation between adaptation and mitigation to be well

addressed. He therefore stated that the SED discussions were "very rich and substantive, balanced, and carried out in a transparent way".

338. Mr. Zou Ji remarked that all SED meetings addressed the two themes of the review in a balanced manner, in terms of the time allocated to them, as well as the format and content of the presentations and discussions. He noted that summary reports on SED 1, 2 and 3, and all presentations and audio and video recordings of the meetings are available on the 2013–2015 review web page.

339. In terms of content, Mr. Zou Ji said the SED had considered a wide range of sources, covering adaptation, mitigation, finance, technology and capacity-building issues. These sources included the contributions of all three working groups of the IPCC to the AR5 and the SYR, and the work of various processes and bodies under the Convention, namely the Adaptation Committee, the Standing Committee on Finance, the CTCN, the TEC, the GCF and the SBI. The SED also heard from United Nations and other organizations, namely the GEF, UNEP, FAO, IEA, the World Bank and WHO. Experts from various regional organizations and regional centres also presented at SED 4.

340. In concluding, Mr. Zou Ji stated that these common traits of the SED sessions illustrate the robustness, transparency, integrity and reliability of the work of the SED. He emphasized that these aspects of the SED meetings have placed it in a position to fulfil its main mandate, namely to ensure the scientific integrity of the 2013–2015 review. He thanked Parties, the secretariat and his co-facilitator for their support and engagement in the work of the SED.

341. Mr. Fischlin made some reflections on the work of the SED and its role within the science–policy interface. He outlined a number of ways in which the SED had brought closer together the policy and scientific communities. He recalled that as mandated by the Parties, the SED had taken into account "the best available scientific knowledge, including the assessment reports of the IPCC". He indicated that this mandate had been fulfilled, since at SED 2, 3 and 4-1, the SED supported Parties in internalizing the key findings contained in the contributions of the three Working Groups of the IPCC to the AR5 and the SYR.

342. He added that at SED 1, 2 and 4, the SED supported Parties in internalizing key findings contained in landmark reports emerging from the recent work of United Nations organizations and other organizations. While underlining that all these findings were relevant to both themes of the 2013–2015 review, he stated that the SED thus facilitated their consideration in a broad and comprehensive policymaking context.

343. Mr. Fischlin then referred to Article 2 of the Convention, in particular the objective to achieve the stabilization of GHG concentrations in the atmosphere "at a level that would prevent dangerous anthropogenic interference with the climate system". While noting that what constitutes a 'danger' is subjective, he stressed that it is our common fear of the threat of climate change that "brought us all together under the Convention", by agreeing on avoiding that danger. On the other hand, he added, Article 2 "divides us", since people may differ on what constitutes danger, and global climate change is impacting us all in different ways. He explained that Article 2 calls for sound information upon which to act after having decided whether the risk is too high, in other words too dangerous, or whether it is an 'acceptable' risk.

344. Mr. Fischlin underlined that the above is what the SED achieved. He stressed that at SED 3, IPCC experts indicated that assessing the adequacy of the upper limit for global warming in the light of Article 2 of the Convention involves both risk assessments and value judgments. He added that risk assessment is what science can provide, sound information on possible dangers. Yet, values also need to be taken into account, which leads to choosing from policy options. Therefore, he said, we need the scientific information, which enables us to make the policy choices. He underscored that in the AR5, the IPCC assessed risks across contexts and through time in a most comprehensive manner, hereby providing an analytical framework that can now be used as a foundation for a collective agreement on how much global warming we choose to accept or tolerate while considering all implications. He expressed confidence that through the SED much of this framework had been mobilized, enabling us now to make these policy choices.

345. In concluding, he expressed the hope that the SED had "empowered" Parties "by informing and supporting policy formulation, not only within the 2013–2015, but also on the road to Paris, taking into account the various values and recognizing that what constitutes an intolerable risk may well differ across sectors, regions and countries". He thanked experts, the secretariat, Mr. Zou Ji and the Parties for the many "excitingly fruitful discussions" that had been held within the SED.

Annex V

Statistics regarding the organization of the structured expert dialogue

	Total	SED 1	SED 2	SED 3	SED 4-1	SED 4-2
Submissions[1]	**20**[2]	8[3]	3[4]	5[5]	2[6]	2[7]
Time of SED Sessions	**34.5**	3	6	12	6	7.5
Presentation Time	**15.5**	1.5	2.5	4.5	2.75	4.25
Discussion Time	**19**	1.5	3.5	7.5	3.25	3.25
No. of Presentations	**60**	**10**	**10**	**16**	**12**	**12**
Overarching	**27**	0	1	2	12	12
Theme 1	**17**	6	4	7	0	0
Theme 2	**16**	4	5	7	0	0
No. of Experts	**73**	**4**	**11**	**18**	**18**	**22**
Overarching	**43**	0	1	2	18	22
Theme 1	**26**	3	5	18	0	0
Theme 2	**27**	1	8	18	0	0
Presenting	**53**	4	9	16	12	12
Responding Only	**20**	0	2	2	6	10
IPCC Experts	**33**	1	6	16	6	4
Other Experts	**40**	3	5	2	12	18
Gender[8]	**53M:20W**	4M:0W	8M:3W	12M:6W	13M:5W	16M:6W
Discussions						
Questions from Parties	**263**	**7**	**50**	**89**	**63**	**54**
Overarching	**111**	0	6	13	38	54
Theme 1	**67**	4	14	40	9	0
Theme 2	**85**	3	30	36	16	0
Responses from Experts	**331**	**15**	**46**	**114**	**87**	**69**
Overarching	**147**	0	11	12	55	69
Theme 1	**77**	7	8	50	12	0
Theme 2	**107**	8	27	52	20	0

[1] Available at <http://unfccc.int/7590.php>
[2] Submissions received from 18 Parties and 2 NGOs
[3] Views on the available information that should be considered at SED1 from 6 Parties and 2 NGOs
[4] Views on the further work of the SED from 3 Parties
[5] Views on the future work of the SED, including the further use of different sources of information from 5 Parties
[6] Views on additional inputs to the SED, on how to conclude the review and on the final ıg of the SBSTA and the SBI to COP 21 from 2 Parties
[7] Views on the resumed fourth session of the SED from 2 Parties
[8] M = men and W = women

Figure 107: Presentation vs. discussion time

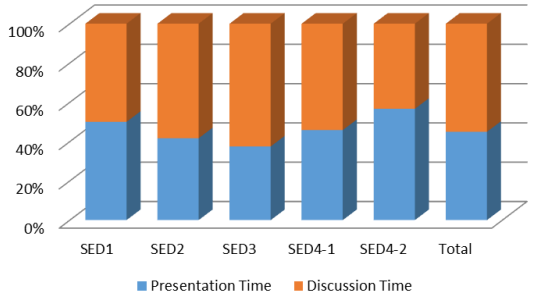


Figure 108: IPCC experts vs. others

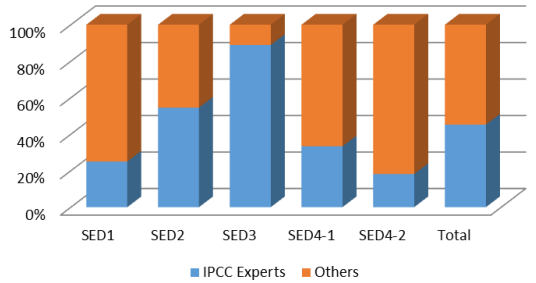
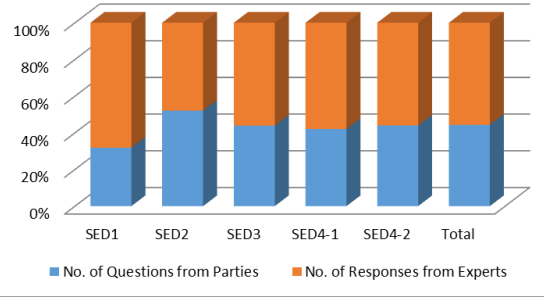


Figure 109: Questions vs. responses



Annex VI

List of experts participating in meetings of the structured expert dialogue

Expert	Affiliation
Amena Yauvoli (SED 4-1, 4-2)[1]	Chair of the Subsidiary Body for Implementation
Andreas Fischlin (SED 1, 4-2)	ETH Zurich, co-facilitator of the structured expert dialogue (SED)
Zou Ji (SED 1, 2, 3, 4-1, 4-2)	Renmin University of China, SED co-facilitator
Keith Alverson (SED 4-1)	United Nations Environment Programme (UNEP)
Alexander Baklanov (SED 4-2)	World Meteorological Organization (WMO)
Vicente Ricardo Barros (SED 4-1)	Intergovernmental Panel on Climate Change (IPCC) Co-chair
Florent Baarsch (SED 4-1)	UNEP
Joern Birkmann (SED 3)	IPCC
Diann Black-Layne (SED 2)	Chair of the Standing Committee on Finance
Gabriel Blanco (SED 3)	IPCC
Christina Chan (SED 4-2)	Co-chair of the Adaptation Committee
Renate Christ (SED 4-1, 4-2)	Secretary of the IPCC
John Christensen (Sed 4-1)	UNEP
David Cooper (SED 4-2)	Secretariat of the Convention on Biological Diversity (CBD)
Purnamita Dasgupta (SED 3)	IPCC
Robert Dixon (SED 2)	Global Environment Facility (GEF)
Kris Ebi (SED 4-1)	World Health Organization (WHO)
Ottmar Edenhofer (SED 3, 4-1)	IPCC, Co-chair of IPCC Working Group III
Christopher Field (SED 1, 3, 4-1)	IPCC, Co-chair of IPCC Working Group II
Luis Gómez-Echeverri (SED 3)	IPCC
Jonathan Gregory (SED 2)	IPCC
Stéphane Hallegatte (SED 4-1)	IPCC
Michael Hanemann (SED 3)	IPCC
Taka Hiraishi (SED 2, 3, 4-1, 4-2)	IPCC, Co-chair of IPCC Task Force on National Greenhouse Gas Inventories
Juan Hoffmaister (SED 4-2)	Co-chair of the Adaptation Committee
Christina Hood (SED 4-1)	International Energy Agency
Christian Huggel (SED 3)	IPCC
Krishna Kumar Kanikicharla (SED 2)	IPCC
Sivan Kartha (SED 3)	IPCC
Reto Knutti (SED 2)	IPCC
Volker Krey (SED 3)	IPCC
Corinne Le Quéré (SED 2, 4.1)	IPCC
Paul Leadley (SED 4-2)	CBD secretariat
Boram Lee (SED 4-2)	World Climate Research Programme
Jeremiah Lengoasa (SED 1, 2, 3, 4-1, 4-2)	WMO

[1] "SED 4-1", for example, stands for the 1st meeting of the fourth session of the structured expert dialogue (SED), while "SED 3" simply means the third session of the SED.

Jason Lowe (SED 1)	Hadley Centre
Katharine Mach (SED 4-2)	IPCC
Diane McFadzien (SED 4-2)	Secretariat of the Pacific Regional Environment Programme (SPREP)
Alexandre Meybeck (SED 4-1)	Food and Agriculture Organization of the United Nations
Leo Meyer (SED 4-1)	IPCC, Head of IPCC Fifth Assessment Report (AR5) Synthesis Report Technical Support Unit (TSU)
Axel Michaelowa (SED 3, 4-2)	IPCC
Guy Midgley (SED 4-2)	IPCC
Jan Minx (SED 3, 4-1, 4-2)	IPCC, Head of IPCC Working Group III TSU
Maria Neira (SED 4-1)	WHO
Leonard Nurse (SED 4-2)	Chairman of the Board of Governors of the Caribbean Community Climate Change Centre
Anne Olhoff (SED 4-1)	UNEP
Lennart Olsson (SED 3)	IPCC
Balgis Osman-Elasha (SED3)	IPCC
Antonio Pflüger (SED 2)	Chair of the Technology Executive Committee
Ramon Pichs Madruga (SED 4-1)	IPCC, Co-Chair of IPCC Working Group III
Gian-Kasper Plattner (SED 4-1)	IPCC, Head of IPCC Working Group I TSU
Clifford Polycarp (SED 4-2)	Green Climate Fund
Hans-Otto Pörtner (SED 3, 4-1)	IPCC
Lars-Otto Reiersen (SED 4-2)	Arctic Monitoring and Assessment Programme
Joeri Rogelj (SED 4-1)	IPCC
Joyashree Roy (SED 3)	IPCC
Asunción Lera St. Clare (SED 3)	IPCC
Thomas Stocker (SED 2, 4-2)	IPCC, Co-Chair of IPCC Working Group I
Deon Terblanche (SED 4-2)	WMO
Griffin Thompson (SED 2)	UNEP, Climate Technology Centre and Network (CTCN)
Petra Tschakert (SED 4-1)	Penn State University / Coordinating Lead Author of chapter 13 of contribution of Working Group II to the AR5
Jukka Uosukainen (SED 4-2)	UNEP, CTCN
Penny Urquhart (SED 3)	IPCC
Sonja Vermeulen (SED 4-2)	Consultative Group for International Agricultural Research / Research Program on Climate Change, Agriculture and Food Security
Detlef van Vuuren (SED 2, 3)	Integrated Assessment Modelling Consortium
Koko Warner (SED 3)	United Nations University
Phillip Williamson (SED 1, 2, 3, 4-2)	CBD secretariat
Jean-Pascal van Ypersele (SED 4-1, 4-2)	IPCC Vice-Chair
Sergio A. Zelaya (SED 4-2)	Secretariat of the United Nations Convention to Combat Desertification

United Nations

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Agenda item 4(b)
Durban Platform for Enhanced Action (decision 1/CP.17)
Adoption of a protocol, another legal instrument, or an agreed outcome with legal force under the Convention applicable to all Parties

ADOPTION OF THE PARIS AGREEMENT

Proposal by the President

Draft decision -/CP.21

The *Conference of the Parties*,

Recalling decision 1/CP.17 on the establishment of the Ad Hoc Working Group on the Durban Platform for Enhanced Action,

Also recalling Articles 2, 3 and 4 of the Convention,

Further recalling relevant decisions of the Conference of the Parties, including decisions 1/CP.16, 2/CP.18, 1/CP.19 and 1/CP.20,

Welcoming the adoption of United Nations General Assembly resolution A/RES/70/1, "Transforming our world: the 2030 Agenda for Sustainable Development", in particular its goal 13, and the adoption of the Addis Ababa Action Agenda of the third International Conference on Financing for Development and the adoption of the Sendai Framework for Disaster Risk Reduction,

Recognizing that climate change represents an urgent and potentially irreversible threat to human societies and the planet and thus requires the widest possible cooperation by all countries, and their participation in an effective and appropriate international response, with a view to accelerating the reduction of global greenhouse gas emissions,

Also recognizing that deep reductions in global emissions will be required in order to achieve the ultimate objective of the Convention and emphasizing the need for urgency in addressing climate change,

Acknowledging that climate change is a common concern of humankind, Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples,

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local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity,

Also acknowledging the specific needs and concerns of developing country Parties arising from the impact of the implementation of response measures and, in this regard, decisions 5/CP.7, 1/CP.10, 1/CP.16 and 8/CP.17,

Emphasizing with serious concern the urgent need to address the significant gap between the aggregate effect of Parties' mitigation pledges in terms of global annual emissions of greenhouse gases by 2020 and aggregate emission pathways consistent with holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels,

Also emphasizing that enhanced pre-2020 ambition can lay a solid foundation for enhanced post-2020 ambition,

Stressing the urgency of accelerating the implementation of the Convention and its Kyoto Protocol in order to enhance pre-2020 ambition,

Recognizing the urgent need to enhance the provision of finance, technology and capacity-building support by developed country Parties, in a predictable manner, to enable enhanced pre-2020 action by developing country Parties,

Emphasizing the enduring benefits of ambitious and early action, including major reductions in the cost of future mitigation and adaptation efforts,

Acknowledging the need to promote universal access to sustainable energy in developing countries, in particular in Africa, through the enhanced deployment of renewable energy,

Agreeing to uphold and promote regional and international cooperation in order to mobilize stronger and more ambitious climate action by all Parties and non-Party stakeholders, including civil society, the private sector, financial institutions, cities and other subnational authorities, local communities and indigenous peoples,

I. ADOPTION

1. *Decides* to adopt the Paris Agreement under the United Nations Framework Convention on Climate Change (hereinafter referred to as "the Agreement") as contained in the annex;

2. *Requests* the Secretary-General of the United Nations to be the Depositary of the Agreement and to have it open for signature in New York, United States of America, from 22 April 2016 to 21 April 2017;

3. *Invites* the Secretary-General to convene a high-level signature ceremony for the Agreement on 22 April 2016;

4. *Also invites* all Parties to the Convention to sign the Agreement at the ceremony to be convened by the Secretary-General, or at their earliest opportunity, and to deposit their respective instruments of ratification, acceptance, approval or accession, where appropriate, as soon as possible;

5. *Recognizes* that Parties to the Convention may provisionally apply all of the provisions of the Agreement pending its entry into force, and *requests* Parties to provide notification of any such provisional application to the Depositary;

6. *Notes* that the work of the Ad Hoc Working Group on the Durban Platform for Enhanced Action, in accordance with decision 1/CP.17, paragraph 4, has been completed;

7. *Decides* to establish the Ad Hoc Working Group on the Paris Agreement under the same arrangement, mutatis mutandis, as those concerning the election of officers to the Bureau of the Ad Hoc Working Group on the Durban Platform for Enhanced Action;[1]

8. *Also decides* that the Ad Hoc Working Group on the Paris Agreement shall prepare for the entry into force of the Agreement and for the convening of the first session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

9. *Further decides* to oversee the implementation of the work programme resulting from the relevant requests contained in this decision;

10. *Requests* the Ad Hoc Working Group on the Paris Agreement to report regularly to the Conference of the Parties on the progress of its work and to complete its work by the first session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

11. *Decides* that the Ad Hoc Working Group on the Paris Agreement shall hold its sessions starting in 2016 in conjunction with the sessions of the Convention subsidiary bodies and shall prepare draft decisions to be recommended through the Conference of the Parties to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement for consideration and adoption at its first session;

II. INTENDED NATIONALLY DETERMINED CONTRIBUTIONS

12. *Welcomes* the intended nationally determined contributions that have been communicated by Parties in accordance with decision 1/CP.19, paragraph 2(b);

13. *Reiterates* its invitation to all Parties that have not yet done so to communicate to the secretariat their intended nationally determined contributions towards achieving the objective of the Convention as set out in its Article 2 as soon as possible and well in advance of the twenty-second session of the Conference of the Parties (November 2016) and in a manner that facilitates the clarity, transparency and understanding of the intended nationally determined contributions;

14. *Requests* the secretariat to continue to publish the intended nationally determined contributions communicated by Parties on the UNFCCC website;

15. *Reiterates* its call to developed country Parties, the operating entities of the Financial Mechanism and any other organizations in a position to do so to provide support for the preparation and communication of the intended nationally determined contributions of Parties that may need such support;

16. *Takes note* of the synthesis report on the aggregate effect of intended nationally determined contributions communicated by Parties by 1 October 2015, contained in document FCCC/CP/2015/7;

17. *Notes* with concern that the estimated aggregate greenhouse gas emission levels in 2025 and 2030 resulting from the intended nationally determined contributions do not fall within least-cost 2 ˚C scenarios but rather lead to a projected level of 55 gigatonnes in 2030, and *also notes* that much greater emission reduction efforts will be required than those associated with the intended nationally determined contributions in order to hold the increase in the global average temperature to below 2 ˚C above pre-industrial levels by

[1] Endorsed by decision 2/CP.18, paragraph 2.

reducing emissions to 40 gigatonnes or to 1.5 ˚C above pre-industrial levels by reducing to a level to be identified in the special report referred to in paragraph 21 below;

18. *Also notes, in this context,* the adaptation needs expressed by many developing country Parties in their intended nationally determined contributions;

19. *Requests* the secretariat to update the synthesis report referred to in paragraph 16 above so as to cover all the information in the intended nationally determined contributions communicated by Parties pursuant to decision 1/CP.20 by 4 April 2016 and to make it available by 2 May 2016;

20. *Decides* to convene a facilitative dialogue among Parties in 2018 to take stock of the collective efforts of Parties in relation to progress towards the long-term goal referred to in Article 4, paragraph 1, of the Agreement and to inform the preparation of nationally determined contributions pursuant to Article 4, paragraph 8, of the Agreement;

21. *Invites* the Intergovernmental Panel on Climate Change to provide a special report in 2018 on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways;

III. DECISIONS TO GIVE EFFECT TO THE AGREEMENT

MITIGATION

22. *Invites* Parties to communicate their first nationally determined contribution no later than when the Party submits its respective instrument of ratification, accession, or approval of the Paris Agreement. If a Party has communicated an intended nationally determined contribution prior to joining the Agreement, that Party shall be considered to have satisfied this provision unless that Party decides otherwise;

23. *Urges* those Parties whose intended nationally determined contribution pursuant to decision 1/CP.20 contains a time frame up to 2025 to communicate by 2020 a new nationally determined contribution and to do so every five years thereafter pursuant to Article 4, paragraph 9, of the Agreement;

24. *Requests* those Parties whose intended nationally determined contribution pursuant to decision 1/CP.20 contains a time frame up to 2030 to communicate or update by 2020 these contributions and to do so every five years thereafter pursuant to Article 4, paragraph 9, of the Agreement;

25. *Decides* that Parties shall submit to the secretariat their nationally determined contributions referred to in Article 4 of the Agreement at least 9 to 12 months in advance of the relevant meeting of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement with a view to facilitating the clarity, transparency and understanding of these contributions, including through a synthesis report prepared by the secretariat;

26. *Requests* the Ad Hoc Working Group on the Paris Agreement to develop further guidance on features of the nationally determined contributions for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

27. *Agrees* that the information to be provided by Parties communicating their nationally determined contributions, in order to facilitate clarity, transparency and understanding, may include, as appropriate, inter alia, quantifiable information on the reference point (including, as appropriate, a base year), time frames and/or periods for implementation, scope and coverage, planning processes, assumptions and methodological approaches including those for estimating and accounting for anthropogenic greenhouse gas

emissions and, as appropriate, removals, and how the Party considers that its nationally determined contribution is fair and ambitious, in the light of its national circumstances, and how it contributes towards achieving the objective of the Convention as set out in its Article 2;

28. *Requests* the Ad Hoc Working Group on the Paris Agreement to develop further guidance for the information to be provided by Parties in order to facilitate clarity, transparency and understanding of nationally determined contributions for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

29. *Also requests* the Subsidiary Body for Implementation to develop modalities and procedures for the operation and use of the public registry referred to in Article 4, paragraph 12, of the Agreement, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

30. *Further requests* the secretariat to make available an interim public registry in the first half of 2016 for the recording of nationally determined contributions submitted in accordance with Article 4 of the Agreement, pending the adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement of the modalities and procedures referred to in paragraph 29 above;

31. *Requests* the Ad Hoc Working Group on the Paris Agreement to elaborate, drawing from approaches established under the Convention and its related legal instruments as appropriate, guidance for accounting for Parties' nationally determined contributions, as referred to in Article 4, paragraph 13, of the Agreement, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session, which ensures that:

(a) Parties account for anthropogenic emissions and removals in accordance with methodologies and common metrics assessed by the Intergovernmental Panel on Climate Change and adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

(b) Parties ensure methodological consistency, including on baselines, between the communication and implementation of nationally determined contributions;

(c) Parties strive to include all categories of anthropogenic emissions or removals in their nationally determined contributions and, once a source, sink or activity is included, continue to include it;

(d) Parties shall provide an explanation of why any categories of anthropogenic emissions or removals are excluded;

32. *Decides* that Parties shall apply the guidance mentioned in paragraph 31 above to the second and subsequent nationally determined contributions and that Parties may elect to apply such guidance to their first nationally determined contribution;

33. *Also decides* that the Forum on the Impact of the Implementation of response measures, under the subsidiary bodies, shall continue, and shall serve the Agreement;

34. *Further decides* that the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation shall recommend, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session, the modalities, work programme and functions of the Forum on the Impact of the Implementation of response measures to address the effects of the implementation of response measures under the Agreement by enhancing cooperation amongst Parties on understanding the impacts of mitigation actions under the Agreement

and the exchange of information, experiences, and best practices amongst Parties to raise their resilience to these impacts;*

36. *Invites* Parties to communicate, by 2020, to the secretariat mid-century, long-term low greenhouse gas emission development strategies in accordance with Article 4, paragraph 19, of the Agreement, and *requests* the secretariat to publish on the UNFCCC website Parties' low greenhouse gas emission development strategies as communicated;

37. *Requests* the Subsidiary Body for Scientific and Technological Advice to develop and recommend the guidance referred to under Article 6, paragraph 2, of the Agreement for adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session, including guidance to ensure that double counting is avoided on the basis of a corresponding adjustment by Parties for both anthropogenic emissions by sources and removals by sinks covered by their nationally determined contributions under the Agreement;

38. *Recommends* that the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement adopt rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Agreement on the basis of:

(a) Voluntary participation authorized by each Party involved;

(b) Real, measurable, and long-term benefits related to the mitigation of climate change;

(c) Specific scopes of activities;

(d) Reductions in emissions that are additional to any that would otherwise occur;

(e) Verification and certification of emission reductions resulting from mitigation activities by designated operational entities;

(f) Experience gained with and lessons learned from existing mechanisms and approaches adopted under the Convention and its related legal instruments;

39. *Requests* the Subsidiary Body for Scientific and Technological Advice to develop and recommend rules, modalities and procedures for the mechanism referred to in paragraph 38 above for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

40. *Also requests* the Subsidiary Body for Scientific and Technological Advice to undertake a work programme under the framework for non-market approaches to sustainable development referred to in Article 6, paragraph 8, of the Agreement, with the objective of considering how to enhance linkages and create synergy between, inter alia, mitigation, adaptation, finance, technology transfer and capacity-building, and how to facilitate the implementation and coordination of non-market approaches;

41. *Further requests* the Subsidiary Body for Scientific and Technological Advice to recommend a draft decision on the work programme referred to in paragraph 40 above, taking into account the views of Parties, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

ADAPTATION

* Paragraph 35 has been deleted, and subsequent paragraph numbering and cross references to other paragraphs within the document will be amended at a later stage.

42. *Requests* the Adaptation Committee and the Least Developed Countries Expert Group to jointly develop modalities to recognize the adaptation efforts of developing country Parties, as referred to in Article 7, paragraph 3, of the Agreement, and make recommendations for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

43. *Also requests* the Adaptation Committee, taking into account its mandate and its second three-year workplan, and with a view to preparing recommendations for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session:

(a) To review, in 2017, the work of adaptation-related institutional arrangements under the Convention, with a view to identifying ways to enhance the coherence of their work, as appropriate, in order to respond adequately to the needs of Parties;

(b) To consider methodologies for assessing adaptation needs with a view to assisting developing countries, without placing an undue burden on them;

44. *Invites* all relevant United Nations agencies and international, regional and national financial institutions to provide information to Parties through the secretariat on how their development assistance and climate finance programmes incorporate climate-proofing and climate resilience measures;

45. *Requests* Parties to strengthen regional cooperation on adaptation where appropriate and, where necessary, establish regional centres and networks, in particular in developing countries, taking into account decision 1/CP.16, paragraph 13;

46. *Also requests* the Adaptation Committee and the Least Developed Countries Expert Group, in collaboration with the Standing Committee on Finance and other relevant institutions, to develop methodologies, and make recommendations for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session on:

(a) Taking the necessary steps to facilitate the mobilization of support for adaptation in developing countries in the context of the limit to global average temperature increase referred to in Article 2 of the Agreement;

(b) Reviewing the adequacy and effectiveness of adaptation and support referred to in Article 7, paragraph 14(c), of the Agreement;

47. *Further requests* the Green Climate Fund to expedite support for the least developed countries and other developing country Parties for the formulation of national adaptation plans, consistent with decisions 1/CP.16 and 5/CP.17, and for the subsequent implementation of policies, projects and programmes identified by them;

LOSS AND DAMAGE

48. *Decides* on the continuation of the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts, following the review in 2016;

49. *Requests* the Executive Committee of the Warsaw International Mechanism to establish a clearinghouse for risk transfer that serves as a repository for information on insurance and risk transfer, in order to facilitate the efforts of Parties to develop and implement comprehensive risk management strategies;

50. *Also requests* the Executive Committee of the Warsaw International Mechanism to establish, according to its procedures and mandate, a task force to complement, draw upon the work of and involve, as appropriate, existing bodies and expert groups under the Convention including the Adaptation Committee and the Least Developed Countries Expert Group, as well as relevant organizations and expert bodies outside the Convention, to

develop recommendations for integrated approaches to avert, minimize and address displacement related to the adverse impacts of climate change;

51. *Further requests* the Executive Committee of the Warsaw International Mechanism to initiate its work, at its next meeting, to operationalize the provisions referred to in paragraphs 49 and 50 above, and to report on progress thereon in its annual report;

52. *Agrees* that Article 8 of the Agreement does not involve or provide a basis for any liability or compensation;

FINANCE

53. *Decides* that, in the implementation of the Agreement, financial resources provided to developing countries should enhance the implementation of their policies, strategies, regulations and action plans and their climate change actions with respect to both mitigation and adaptation to contribute to the achievement of the purpose of the Agreement as defined in Article 2;

54. *Also decides* that, in accordance with Article 9, paragraph 3, of the Agreement, developed countries intend to continue their existing collective mobilization goal through 2025 in the context of meaningful mitigation actions and transparency on implementation; prior to 2025 the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall set a new collective quantified goal from a floor of USD 100 billion per year, taking into account the needs and priorities of developing countries;

55. *Recognizes* the importance of adequate and predictable financial resources, including for results-based payments, as appropriate, for the implementation of policy approaches and positive incentives for reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks; as well as alternative policy approaches, such as joint mitigation and adaptation approaches for the integral and sustainable management of forests; while reaffirming the importance of non-carbon benefits associated with such approaches; encouraging the coordination of support from, inter alia, public and private, bilateral and multilateral sources, such as the Green Climate Fund, and alternative sources in accordance with relevant decisions by the Conference of the Parties;

56. *Decides* to initiate, at its twenty-second session, a process to identify the information to be provided by Parties, in accordance with Article 9, paragraph 5, of the Agreement with the view to providing a recommendation for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

57. *Also decides* to ensure that the provision of information in accordance with Article 9, paragraph 7 of the Agreement shall be undertaken in accordance with modalities, procedures and guidelines referred to in paragraph 96 below;

58. *Requests* Subsidiary Body for Scientific and Technological Advice to develop modalities for the accounting of financial resources provided and mobilized through public interventions in accordance with Article 9, paragraph 7, of the Agreement for consideration by the Conference of the Parties at its twenty-fourth session (November 2018), with the view to making a recommendation for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

59. *Decides* that the Green Climate Fund and the Global Environment Facility, the entities entrusted with the operation of the Financial Mechanism of the Convention, as well as the Least Developed Countries Fund and the Special Climate Change Fund, administered by the Global Environment Facility, shall serve the Agreement;

60. *Recognizes* that the Adaptation Fund may serve the Agreement, subject to relevant decisions by the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol and the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

61. *Invites* the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol to consider the issue referred to in paragraph 60 above and make a recommendation to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

62. *Recommends* that the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall provide guidance to the entities entrusted with the operation of the Financial Mechanism of the Convention on the policies, programme priorities and eligibility criteria related to the Agreement for transmission by the Conference of the Parties;

63. *Decides* that the guidance to the entities entrusted with the operations of the Financial Mechanism of the Convention in relevant decisions of the Conference of the Parties, including those agreed before adoption of the Agreement, shall apply mutatis mutandis;

64. *Also decides* that the Standing Committee on Finance shall serve the Agreement in line with its functions and responsibilities established under the Conference of the Parties;

65. *Urges* the institutions serving the Agreement to enhance the coordination and delivery of resources to support country-driven strategies through simplified and efficient application and approval procedures, and through continued readiness support to developing country Parties, including the least developed countries and small island developing States, as appropriate;

TECHNOLOGY DEVELOPMENT AND TRANSFER

66. *Takes note of* the interim report of the Technology Executive Committee on guidance on enhanced implementation of the results of technology needs assessments as referred to in document FCCC/SB/2015/INF.3;

67. *Decides* to strengthen the Technology Mechanism and requests the Technology Executive Committee and the Climate Technology Centre and Network, in supporting the implementation of the Agreement, to undertake further work relating to, inter alia:

(a) Technology research, development and demonstration;

(b) The development and enhancement of endogenous capacities and technologies;

68. *Requests* the Subsidiary Body for Scientific and Technological Advice to initiate, at its forty-fourth session (May 2016), the elaboration of the technology framework established under Article 10, paragraph 4, of the Agreement and to report on its findings to the Conference of the Parties, with a view to the Conference of the Parties making a recommendation on the framework to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement for consideration and adoption at its first session, taking into consideration that the framework should facilitate, inter alia:

(a) The undertaking and updating of technology needs assessments, as well as the *enhanced* implementation of their results, particularly technology action plans and project ideas, through the preparation of bankable projects;

(b) The provision of enhanced financial and technical support for the implementation of the results of the technology needs assessments;

(c) The assessment of technologies that are ready for transfer;

(d) The enhancement of enabling environments for and the addressing of barriers to the development and transfer of socially and environmentally sound technologies*;*

69. *Decides* that the Technology Executive Committee and the Climate Technology Centre and Network shall report to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement, through the subsidiary bodies, on their activities to support the implementation of the Agreement;

70. *Also decides* to undertake a periodic assessment of the effectiveness of and the adequacy of the support provided to the Technology Mechanism in supporting the implementation of the Agreement on matters relating to technology development and transfer;

71. *Requests* the Subsidiary Body for Implementation to initiate, at its forty-fourth session , the elaboration of the scope of and modalities for the periodic assessment referred to in paragraph 70 above, taking into account the review of the Climate Technology Centre and Network as referred to in decision 2/CP.17, annex VII, paragraph 20 and the modalities for the global stocktake referred to in Article 14 of the Agreement, for consideration and adoption by the Conference of the Parties at its twenty-fifth session (November 2019);

CAPACITY-BUILDING

72. *Decides* to establish the Paris Committee on Capacity-building whose aim will be to address gaps and needs, both current and emerging, in implementing capacity-building in developing country Parties and further enhancing capacity-building efforts, including with regard to coherence and coordination in capacity-building activities under the Convention;

73. *Also decides* that the Paris Committee on Capacity-building will manage and oversee the work plan mentioned in paragraph 74 below;

74. *Further decides* to launch a work plan for the period 2016–2020 with the following activities:

(a) Assessing how to increase synergies through cooperation and avoid duplication among existing bodies established under the Convention that implement capacity-building activities, including through collaborating with institutions under and outside the Convention;

(b) Identifying capacity gaps and needs and recommending ways to address them;

(c) Promoting the development and dissemination of tools and methodologies for the implementation of capacity-building;

(d) Fostering global, regional, national and subnational cooperation;

(e) Identifying and collecting good practices, challenges, experiences, and lessons learned from work on capacity-building by bodies established under the Convention;

(f) Exploring how developing country Parties can take ownership of building and maintaining capacity over time and spac*e;*

(g) Identifying opportunities to strengthen capacity at the national, regional, and subnational level;

(h) Fostering dialogue, coordination, collaboration and coherence among relevant processes and initiatives under the Convention, including through exchanging

information on capacity-building activities and strategies of bodies established under the Convention;

(i) Providing guidance to the secretariat on the maintenance and further development of the web-based capacity-building portal;

75. *Decides* that the Paris Committee on Capacity-building will annually focus on an area or theme related to enhanced technical exchange on capacity-building, with the purpose of maintaining up-to-date knowledge on the successes and challenges in building capacity effectively in a particular area;

76. *Requests* the Subsidiary Body for Implementation to organize annual in-session meetings of the Paris Committee on Capacity-building;

77. *Also requests* the Subsidiary Body for Implementation to develop the terms of reference for the Paris Committee on Capacity-building, in the context of the third comprehensive review of the implementation of the capacity-building framework, also taking into account paragraphs 75, 76, 77 and 78 above and paragraphs 82 and 83 below, with a view to recommending a draft decision on this matter for consideration and adoption by the Conference of the Parties at its twenty-second session;

78. *Invites* Parties to submit their views on the membership of the Paris Committee on Capacity-building by 9 March 2016;[2]

79. *Requests* the secretariat to compile the submissions referred to in paragraph 78 above into a miscellaneous document for consideration by the Subsidiary Body for Implementation at its forty-fourth session;

80. *Decides* that the inputs to the Paris Committee on Capacity-building will include, inter alia, submissions, the outcome of the third comprehensive review of the implementation of the capacity-building framework, the secretariat's annual synthesis report on the implementation of the framework for capacity-building in developing countries, the secretariat's compilation and synthesis report on capacity-building work of bodies established under the Convention and its Kyoto Protocol, and reports on the Durban Forum and the capacity-building portal;

81. *Requests* the Paris Committee on Capacity-building to prepare annual technical progress reports on its work, and to make these reports available at the sessions of the Subsidiary Body for Implementation coinciding with the sessions of the Conference of the Parties;

82. *Also requests* the Conference of the Parties at its twenty-fifth session (November 2019), to review the progress, need for extension, the effectiveness and enhancement of the Paris Committee on Capacity-building and to take any action it considers appropriate, with a view to making recommendations to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session on enhancing institutional arrangements for capacity-building consistent with Article 11, paragraph 5, of the Agreement;

83. *Calls upon* all Parties to ensure that education, training and public awareness, as reflected in Article 6 of the Convention and in Article 12 of the Agreement are adequately considered in their contribution to capacity-building;

84. *Invites* the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session to explore ways of enhancing the implementation of

[2] Parties should submit their views via the submissions portal at <http://www.unfccc.int/5900>.

training, public awareness, public participation and public access to information so as to enhance actions under the Agreement;

TRANSPARENCY OF ACTION AND SUPPORT

85. *Decides* to establish a Capacity-building Initiative for Transparency in order to build institutional and technical capacity, both pre- and post-2020. This initiative will support developing country Parties, upon request, in meeting enhanced transparency requirements as defined in Article 13 of the Agreement in a timely manner;

86. *Also decides* that the Capacity-building Initiative for Transparency will aim:

(a) To strengthen national institutions for transparency-related activities in line with national priorities;

(b) To provide relevant tools, training and assistance for meeting the provisions stipulated in Article 13 of the Agreement;

(c) To assist in the improvement of transparency over time;

87. *Urges and requests* the Global Environment Facility to make arrangements to support the establishment and operation of the Capacity-building Initiative for Transparency as a priority reporting-related need, including through voluntary contributions to support developing countries in the sixth replenishment of the Global Environment Facility and future replenishment cycles, to complement existing support under the Global Environment Facility;

88. *Decides* to assess the implementation of the Capacity-building Initiative for Transparency in the context of the seventh review of the financial mechanism;

89. *Requests* that the Global Environment Facility, as an operating entity of the financial mechanism include in its annual report to the Conference of the Parties the progress of work in the design, development and implementation of the Capacity-building Initiative for Transparency referred to in paragraph 85 above starting in 2016;

90. *Decides* that, in accordance with Article 13, paragraph 2, of the Agreement, developing countries shall be provided flexibility in the implementation of the provisions of that Article, including in the scope, frequency and level of detail of reporting, and in the scope of review, and that the scope of review could provide for in-country reviews to be optional, while such flexibilities shall be reflected in the development of modalities, procedures and guidelines referred to in paragraph 92 below;

91. *Also decides* that all Parties, except for the least developed country Parties and small island developing States, shall submit the information referred to in Article 13, paragraphs 7, 8, 9 and 10, as appropriate, no less frequently than on a biennial basis, and that the least developed country Parties and small island developing States may submit this information at their discretion;

92. *Requests* the Ad Hoc Working Group on the Paris Agreement to develop recommendations for modalities, procedures and guidelines in accordance with Article 13, paragraph 13, of the Agreement, and to define the year of their first and subsequent review and update, as appropriate, at regular intervals, for consideration by the Conference of the Parties, at its twenty-fourth session, with a view to forwarding them to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement for adoption at its first session;

93. *Also requests* the Ad Hoc Working Group on the Paris Agreement in developing the recommendations for the modalities, procedures and guidelines referred to in paragraph 92 above to take into account, inter alia:

(a) The importance of facilitating improved reporting and transparency over time;

(b) The need to provide flexibility to those developing country Parties that need it in the light of their capacities;

(c) The need to promote transparency, accuracy, completeness, consistency, and comparability;

(d) The need to avoid duplication as well as undue burden on Parties and the secretariat;

(e) The need to ensure that Parties maintain at least the frequency and quality of reporting in accordance with their respective obligations under the Convention;

(f) The need to ensure that double counting is avoided;

(g) The need to ensure environmental integrity;

94. *Further requests* the Ad Hoc Working Group on the Paris Agreement, when developing the modalities, procedures and guidelines referred to in paragraph 92 above, to draw on the experiences from and take into account other on-going relevant processes under the Convention;

95. *Requests* the Ad Hoc Working Group on the Paris Agreement, when developing modalities, procedures and guidelines referred to in paragraph 92 above, to consider, inter alia:

(a) The types of flexibility available to those developing countries that need it on the basis of their capacities;

(b) The consistency between the methodology communicated in the nationally determined contribution and the methodology for reporting on progress made towards achieving individual Parties' respective nationally determined contribution;

(c) That Parties report information on adaptation action and planning including, if appropriate**,** their national adaptation plans, with a view to collectively exchanging information and sharing lessons learned;

(d) Support provided, enhancing delivery of support for both adaptation and mitigation through, inter alia, the common tabular formats for reporting support, and taking into account issues considered by the Subsidiary Body for Scientific and Technological Advice on methodologies for reporting on financial information, and enhancing the reporting by developing countries on support received, including the use, impact and estimated results thereof;

(e) Information in the biennial assessments and other reports of the Standing Committee on Finance and other relevant bodies under the Convention;

(f) Information on the social and economic impact of response measures;

96. *Also requests* the Ad Hoc Working Group on the Paris Agreement, when developing recommendations for modalities, procedures and guidelines referred to in paragraph 92 above, to enhance the transparency of support provided in accordance with Article 9 of the Agreement;

97. *Further requests* the Ad Hoc Working Group on the Paris Agreement to report on the progress of work on the modalities, procedures and guidelines referred to in paragraph

92 above to future sessions of the Conference of the Parties, and that this work be concluded no later than 2018;

98. *Decides* that the modalities, procedures and guidelines developed under paragraph 92 above, shall be applied upon the entry into force of the Paris Agreement;

99. *Also decides* that the modalities, procedures and guidelines of this transparency framework shall build upon and eventually supersede the measurement, reporting and verification system established by decision 1/CP.16, paragraphs 40 to 47 and 60 to 64, and decision 2/CP.17, paragraphs 12 to 62, immediately following the submission of the final biennial reports and biennial update reports;

GLOBAL STOCKTAKE

100. *Requests* the Ad Hoc Working Group on the Paris Agreement to identify the sources of input for the global stocktake referred to in Article 14 of the Agreement and to report to the Conference of the Parties, with a view to the Conference of the Parties making a recommendation to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement for consideration and adoption at its first session, including, but not limited to:

(a) Information on:

(i) The overall effect of the nationally determined contributions communicated by Parties;

(ii) The state of adaptation efforts, support, experiences and priorities from the communications referred to in Article 7, paragraphs 10 and 11, of the Agreement, and reports referred to in Article 13, paragraph 7, of the Agreement;

(iii) The mobilization and provision of support;

(b) The latest reports of the Intergovernmental Panel on Climate Change;

(c) Reports of the subsidiary bodies;

101. *Also requests* the Subsidiary Body for Scientific and Technological Advice to provide advice on how the assessments of the Intergovernmental Panel on Climate Change can inform the global stocktake of the implementation of the Agreement pursuant to its Article 14 of the Agreement and to report on this matter to the Ad Hoc Working Group on the Paris Agreement at its second session;

102. *Further requests* the Ad Hoc Working Group on the Paris Agreement to develop modalities for the global stocktake referred to in Article 14 of the Agreement and to report to the Conference of the Parties, with a view to making a recommendation to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement for consideration and adoption at its first session;

FACILITATING IMPLEMENTATION AND COMPLIANCE

103. *Decides* that the committee referred to in Article 15, paragraph 2, of the Agreement shall consist of 12 members with recognized competence in relevant scientific, technical, socio-economic or legal fields, to be elected by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement on the basis of equitable geographical representation, with two members each from the five regional groups of the United Nations and one member each from the small island developing States and the least developed countries, while taking into account the goal of gender balance;

104. *Requests* the Ad Hoc Working Group on the Paris Agreement to develop the modalities and procedures for the effective operation of the committee referred to in Article 15, paragraph 2, of the Agreement, with a view to the Ad Hoc Working Group on the Paris

Agreement completing its work on such modalities and procedures for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

FINAL CLAUSES

105. *Also requests* the secretariat, solely for the purposes of Article 21 of the Agreement, to make available on its website on the date of adoption of the Agreement as well as in the report of the Conference of the Parties at its twenty-first session, information on the most up-to-date total and per cent of greenhouse gas emissions communicated by Parties to the Convention in their national communications, greenhouse gas inventory reports, biennial reports or biennial update reports;

IV. ENHANCED ACTION PRIOR TO 2020

106. *Resolves* to ensure the highest possible mitigation efforts in the pre-2020 period, including by:

(a) Urging all Parties to the Kyoto Protocol that have not already done so to ratify and implement the Doha Amendment to the Kyoto Protocol;

(b) Urging all Parties that have not already done so to make and implement a mitigation pledge under the Cancun Agreements;

(c) Reiterating its resolve, as set out in decision 1/CP.19, paragraphs 3 and 4, to accelerate the full implementation of the decisions constituting the agreed outcome pursuant to decision 1/CP.13 and enhance ambition in the pre-2020 period in order to ensure the highest possible mitigation efforts under the Convention by all Parties;

(d) Inviting developing country Parties that have not submitted their first biennial update reports to do so as soon as possible;

(e) Urging all Parties to participate in the existing measurement, reporting and verification processes under the Cancun Agreements, in a timely manner, with a view to demonstrating progress made in the implementation of their mitigation pledges;

107. *Encourages* Parties to promote the voluntary cancellation by Party and non-Party stakeholders, without double counting of units issued under the Kyoto Protocol, including certified emission reductions that are valid for the second commitment period;

108. *Urges* host and purchasing Parties to report transparently on internationally transferred mitigation outcomes, including outcomes used to meet international pledges, and emission units issued under the Kyoto Protocol with a view to promoting environmental integrity and avoiding double counting;

109. *Recognizes* the social, economic and environmental value of voluntary mitigation actions and their co-benefits for adaptation, health and sustainable development;

110. *Resolves* to strengthen, in the period 2016–2020, the existing technical examination process on mitigation as defined in decision 1/CP.19, paragraph 5(a), and decision 1/CP.20, paragraph 19, taking into account the latest scientific knowledge, including by:

(a) Encouraging Parties, Convention bodies and international organizations to engage in this process, including, as appropriate, in cooperation with relevant non-Party stakeholders, to share their experiences and suggestions, including from regional events, and to cooperate in facilitating the implementation of policies, practices and actions identified during this process in accordance with national sustainable development priorities;

(b) Striving to improve, in consultation with Parties, access to and participation in this process by developing country Party and non-Party experts;

(c) Requesting the Technology Executive Committee and the Climate Technology Centre and Network in accordance with their respective mandates:

(i) To engage in the technical expert meetings and enhance their efforts to facilitate and support Parties in scaling up the implementation of policies, practices and actions identified during this process;

(ii) To provide regular updates during the technical expert meetings on the progress made in facilitating the implementation of policies, practices and actions previously identified during this process;

(iii) To include information on their activities under this process in their joint annual report to the Conference of the Parties;

(d) Encouraging Parties to make effective use of the Climate Technology Centre and Network to obtain assistance to develop economically, environmentally and socially viable project proposals in the high mitigation potential areas identified in this process;

111. *Encourages* the operating entities of the Financial Mechanism of the Convention to engage in the technical expert meetings and to inform participants of their contribution to facilitating progress in the implementation of policies, practices and actions identified during the technical examination process;

112. *Requests* the secretariat to organize the process referred to in paragraph 110 above and disseminate its results, including by:

(a) Organizing, in consultation with the Technology Executive Committee and relevant expert organizations, regular technical expert meetings focusing on specific policies, practices and actions representing best practices and with the potential to be scalable and replicable;

(b) Updating, on an annual basis, following the meetings referred to in paragraph 112(a) above and in time to serve as input to the summary for policymakers referred to in paragraph 112(c) below, a technical paper on the mitigation benefits and co-benefits of policies, practices and actions for enhancing mitigation ambition, as well as on options for supporting their implementation, information on which should be made available in a user-friendly online format;

(c) Preparing, in consultation with the champions referred to in paragraph 122 below, a summary for policymakers, with information on specific policies, practices and actions representing best practices and with the potential to be scalable and replicable, and on options to support their implementation, as well as on relevant collaborative initiatives, and publishing the summary at least two months in advance of each session of the Conference of the Parties as input for the high-level event referred to in paragraph 121 below;

113. *Decides* that the process referred to in paragraph 110 above should be organized jointly by the Subsidiary Body for Implementation and the Subsidiary Body for Scientific and Technological Advice and should take place on an ongoing basis until 2020;

114. *Also decides* to conduct in 2017 an assessment of the process referred to in paragraph 110 above so as to improve its effectiveness;

115. *Resolves* to enhance the provision of urgent and adequate finance, technology and capacity-building support by developed country Parties in order to enhance the level of ambition of pre-2020 action by Parties, and in this regard *strongly urges* developed country Parties to scale up their level of financial support, with a concrete roadmap to achieve the

goal of jointly providing USD 100 billion annually by 2020 for mitigation and adaptation while significantly increasing adaptation finance from current levels and to further provide appropriate technology and capacity-building support;

116. *Decides* to conduct a facilitative dialogue in conjunction with the twenty-second session of the Conference of the Parties to assess the progress in implementing decision 1/CP.19, paragraphs 3 and 4, and identify relevant opportunities to enhance the provision of financial resources, including for technology development and transfer and capacity-building support, with a view to identifying ways to enhance the ambition of mitigation efforts by all Parties, including identifying relevant opportunities to enhance the provision and mobilization of support and enabling environments;

117. *Acknowledges* with appreciation the results of the Lima-Paris Action Agenda, which build on the climate summit convened on 23 September 2014 by the Secretary-General of the United Nations;

118. *Welcomes* the efforts of non-Party stakeholders to scale up their climate actions, and *encourages* the registration of those actions in the Non-State Actor Zone for Climate Action platform;[3]

119. *Encourages* Parties to work closely with non-Party stakeholders to catalyse efforts to strengthen mitigation and adaptation action;

120. *Also encourages* non-Party stakeholders to increase their engagement in the processes referred to in paragraph 110 above and paragraph 125 below;

121. *Agrees* to convene, pursuant to decision 1/CP.20, paragraph 21, building on the Lima-Paris Action Agenda and in conjunction with each session of the Conference of the Parties during the period 2016–2020, a high-level event that:

(a) Further strengthens high-level engagement on the implementation of policy options and actions arising from the processes referred to in paragraph 110 above and paragraph 125 below, drawing on the summary for policymakers referred to in paragraph 112(c) above;

(b) Provides an opportunity for announcing new or strengthened voluntary efforts, initiatives and coalitions, including the implementation of policies, practices and actions arising from the processes referred to in paragraph 110 above and paragraph 125 below and presented in the summary for policymakers referred to in paragraph 112(c) above;

(c) Takes stock of related progress and recognizes new or strengthened voluntary efforts, initiatives and coalitions;

(d) Provides meaningful and regular opportunities for the effective high-level engagement of dignitaries of Parties, international organizations, international cooperative initiatives and non-Party stakeholders;

122. *Decides* that two high-level champions shall be appointed to act on behalf of the President of the Conference of the Parties to facilitate through strengthened high-level engagement in the period 2016–2020 the successful execution of existing efforts and the scaling-up and introduction of new or strengthened voluntary efforts, initiatives and coalitions, including by:

[3] <http://climateaction.unfccc.int/>.

(a) Working with the Executive Secretary and the current and incoming Presidents of the Conference of the Parties to coordinate the annual high-level event referred to in paragraph 121 above;

(b) Engaging with interested Parties and non-Party stakeholders, including to further the voluntary initiatives of the Lima-Paris Action Agenda;

(c) Providing guidance to the secretariat on the organization of technical expert meetings referred to in paragraph 112(a) above and paragraph 130(a) below;

123. *Also decides* that the high-level champions referred to in paragraph 122 above should normally serve for a term of two years, with their terms overlapping for a full year to ensure continuity, such that:

(a) The President of the Conference of the Parties of the twenty-first session should appoint one champion, who should serve for one year from the date of the appointment until the last day of the Conference of the Parties at its twenty-second session;

(b) The President of the Conference of the Parties of the twenty-second session should appoint one champion who should serve for two years from the date of the appointment until the last day of the Conference of the Parties at its twenty-third session (November 2017);

(c) Thereafter, each subsequent President of the Conference of the Parties should appoint one champion who should serve for two years and succeed the previously appointed champion whose term has ended;

124. *Invites* all interested Parties and relevant organizations to provide support for the work of the champions referred to in paragraph 122 above;

125. *Decides* to launch, in the period 2016–2020, a technical examination process on adaptation;

126. *Also decides* that the technical examination process on adaptation referred to in paragraph 125 above will endeavour to identify concrete opportunities for strengthening resilience, reducing vulnerabilities and increasing the understanding and implementation of adaptation actions;

127. *Further decides* that the technical examination process referred to in paragraph 125 above should be organized jointly by the Subsidiary Body for Implementation and the Subsidiary Body for Scientific and Technological Advice, and conducted by the Adaptation Committee;

128. *Decides* that the process referred to in paragraph 125 above will be pursued by:

(a) Facilitating the sharing of good practices, experiences and lessons learned;

(b) Identifying actions that could significantly enhance the implementation of adaptation actions, including actions that could enhance economic diversification and have mitigation co-benefits;

(c) Promoting cooperative action on adaptation;

(d) Identifying opportunities to strengthen enabling environments and enhance the provision of support for adaptation in the context of specific policies, practices and actions;

129. *Also decides* that the technical examination process on adaptation referred to in paragraph 125 above will take into account the process, modalities, outputs, outcomes and lessons learned from the technical examination process on mitigation referred to in paragraph 110 above;

130. *Requests* the secretariat to support the technical examination process referred to in paragraph 125 above by:

(a) Organizing regular technical expert meetings focusing on specific policies, strategies and actions;

(b) Preparing annually, on the basis of the meetings referred to in paragraph 130(a) above and in time to serve as an input to the summary for policymakers referred to in paragraph 112(c) above, a technical paper on opportunities to enhance adaptation action, as well as options to support their implementation, information on which should be made available in a user-friendly online format;

131. *Decides* that in conducting the process referred to in paragraph 125 above, the Adaptation Committee will engage with and explore ways to take into account, synergize with and build on the existing arrangements for adaptation-related work programmes, bodies and institutions under the Convention so as to ensure coherence and maximum value;

132. *Also decides* to conduct, in conjunction with the assessment referred to in paragraph 120 above, an assessment of the process referred to in paragraph 125 above, so as to improve its effectiveness;

133. *Invites* Parties and observer organizations to submit information on the opportunities referred to in paragraph 126 above by 3 February 2016;

V. NON-PARTY STAKEHOLDERS

134. *Welcomes* the efforts of all non-Party stakeholders to address and respond to climate change, including those of civil society, the private sector, financial institutions, cities and other subnational authorities;

135. *Invites* the non-Party stakeholders referred to in paragraph 134 above to scale up their efforts and support actions to reduce emissions and/or to build resilience and decrease vulnerability to the adverse effects of climate change and demonstrate these efforts via the Non-State Actor Zone for Climate Action platform[4] referred to in paragraph 118 above;

136. *Recognizes* the need to strengthen knowledge, technologies, practices and efforts of local communities and indigenous peoples related to addressing and responding to climate change, and *establishes* a platform for the exchange of experiences and sharing of best practices on mitigation and adaptation in a holistic and integrated manner;

137. *Also recognizes* the important role of providing incentives for emission reduction activities, including tools such as domestic policies and carbon pricing;

VI. ADMINISTRATIVE AND BUDGETARY MATTERS

138. *Takes note* of the estimated budgetary implications of the activities to be undertaken by the secretariat referred to in this decision and requests that the actions of the secretariat called for in this decision be undertaken subject to the availability of financial resources;

139. *Emphasizes* the urgency of making additional resources available for the implementation of the relevant actions, including actions referred to in this decision, and the implementation of the work programme referred to in paragraph 9 above;

[4] <http://climateaction.unfccc.int/>.

140. *Urges* Parties to make voluntary contributions for the timely implementation of this decision.

Annex

PARIS AGREEMENT

The Parties to this Agreement,

Being Parties to the United Nations Framework Convention on Climate Change, hereinafter referred to as "the Convention",

Pursuant to the Durban Platform for Enhanced Action established by decision 1/CP.17 of the Conference of the Parties to the Convention at its seventeenth session,

In pursuit of the objective of the Convention, and being guided by its principles, including the principle of equity and common but differentiated responsibilities and respective capabilities, in the light of different national circumstances,

Recognizing the need for an effective and progressive response to the urgent threat of climate change on the basis of the best available scientific knowledge,

Also recognizing the specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, as provided for in the Convention,

Taking full account of the specific needs and special situations of the least developed countries with regard to funding and transfer of technology,

Recognizing that Parties may be affected not only by climate change, but also by the impacts of the measures taken in response to it,

Emphasizing the intrinsic relationship that climate change actions, responses and impacts have with equitable access to sustainable development and eradication of poverty,

Recognizing the fundamental priority of safeguarding food security and ending hunger, and the particular vulnerabilities of food production systems to the adverse impacts of climate change,

Taking into account the imperatives of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities,

Acknowledging that climate change is a common concern of humankind, Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity,

Recognizing the importance of the conservation and enhancement, as appropriate, of sinks and reservoirs of the greenhouse gases referred to in the Convention,

Noting the importance of ensuring the integrity of all ecosystems, including oceans, and the protection of biodiversity, recognized by some cultures as Mother Earth, and noting the importance for some of the concept of "climate justice", when taking action to address climate change,

Affirming the importance of education, training, public awareness, public participation, public access to information and cooperation at all levels on the matters addressed in this Agreement,

Recognizing the importance of the engagements of all levels of government and various actors, in accordance with respective national legislations of Parties, in addressing climate change,

Also recognizing that sustainable lifestyles and sustainable patterns of consumption and production, with developed country Parties taking the lead, play an important role in addressing climate change,

Have agreed as follows:

Article 1

For the purpose of this Agreement, the definitions contained in Article 1 of the Convention shall apply. In addition:

1. "Convention" means the United Nations Framework Convention on Climate Change, adopted in New York on 9 May 1992.
2. "Conference of the Parties" means the Conference of the Parties to the Convention.
3. "Party" means a Party to this Agreement.

Article 2

1. This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:
   (a) Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;
   (b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production;
   (c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.
2. This Agreement will be implemented to reflect equity and the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.

Article 3

As nationally determined contributions to the global response to climate change, all Parties are to undertake and communicate ambitious efforts as defined in Articles 4, 7, 9, 10, 11 and 13 with the view to achieving the purpose of this Agreement as set out in Article 2. The efforts of all Parties will represent a progression over time, while recognizing the need to support developing country Parties for the effective implementation of this Agreement.

Article 4

1. In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty.
2. Each Party shall prepare, communicate and maintain successive nationally determined contributions that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions.
3. Each Party's successive nationally determined contribution will represent a progression beyond the Party's then current nationally determined contribution and reflect its highest possible ambition, reflecting its common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.
4. Developed country Parties should continue taking the lead by undertaking economy-wide absolute emission reduction targets. Developing country Parties should continue enhancing their mitigation efforts, and are encouraged to move over time towards economy-wide emission reduction or limitation targets in the light of different national circumstances.
5. Support shall be provided to developing country Parties for the implementation of this Article, in accordance with Articles 9, 10 and 11, recognizing that enhanced support for developing country Parties will allow for higher ambition in their actions.

6. The least developed countries and small island developing States may prepare and communicate strategies, plans and actions for low greenhouse gas emissions development reflecting their special circumstances.

7. Mitigation co-benefits resulting from Parties' adaptation actions and/or economic diversification plans can contribute to mitigation outcomes under this Article.

8. In communicating their nationally determined contributions, all Parties shall provide the information necessary for clarity, transparency and understanding in accordance with decision 1/CP.21 and any relevant decisions of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

9. Each Party shall communicate a nationally determined contribution every five years in accordance with decision 1/CP.21 and any relevant decisions of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement and be informed by the outcomes of the global stocktake referred to in Article 14.

10. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall consider common time frames for nationally determined contributions at its first session.

11. A Party may at any time adjust its existing nationally determined contribution with a view to enhancing its level of ambition, in accordance with guidance adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

12. Nationally determined contributions communicated by Parties shall be recorded in a public registry maintained by the secretariat.

13. Parties shall account for their nationally determined contributions. In accounting for anthropogenic emissions and removals corresponding to their nationally determined contributions, Parties shall promote environmental integrity, transparency, accuracy, completeness, comparability and consistency, and ensure the avoidance of double counting, in accordance with guidance adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

14. In the context of their nationally determined contributions, when recognizing and implementing mitigation actions with respect to anthropogenic emissions and removals, Parties should take into account, as appropriate, existing methods and guidance under the Convention, in the light of the provisions of paragraph 13 of this Article.

15. Parties shall take into consideration in the implementation of this Agreement the concerns of Parties with economies most affected by the impacts of response measures, particularly developing country Parties.

16. Parties, including regional economic integration organizations and their member States, that have reached an agreement to act jointly under paragraph 2 of this Article shall notify the secretariat of the terms of that agreement, including the emission level allocated to each Party within the relevant time period, when they communicate their nationally determined contributions. The secretariat shall in turn inform the Parties and signatories to the Convention of the terms of that agreement.

17. Each party to such an agreement shall be responsible for its emission level as set out in the agreement referred to in paragraph 16 above in accordance with paragraphs 13 and 14 of this Article and Articles 13 and 15.

18. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization which is itself a Party to this Agreement, each member State of that regional economic integration organization individually, and together with the regional economic integration organization, shall be responsible for its emission level as set out in the agreement communicated under paragraph 16 of this Article in accordance with paragraphs 13 and 14 of this Article and Articles 13 and 15.

19. All Parties should strive to formulate and communicate long-term low greenhouse gas emission development strategies, mindful of Article 2 taking into account their common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.

Article 5

1. Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases as referred to in Article 4, paragraph 1(d), of the Convention, including forests.

2. Parties are encouraged to take action to implement and support, including through results-based payments, the existing framework as set out in related guidance and decisions already agreed under the Convention for: policy approaches and positive incentives for activities relating to reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon

stocks in developing countries; and alternative policy approaches, such as joint mitigation and adaptation approaches for the integral and sustainable management of forests, while reaffirming the importance of incentivizing, as appropriate, non-carbon benefits associated with such approaches.

Article 6

1. Parties recognize that some Parties choose to pursue voluntary cooperation in the implementation of their nationally determined contributions to allow for higher ambition in their mitigation and adaptation actions and to promote sustainable development and environmental integrity.
2. Parties shall, where engaging on a voluntary basis in cooperative approaches that involve the use of internationally transferred mitigation outcomes towards nationally determined contributions, promote sustainable development and ensure environmental integrity and transparency, including in governance, and shall apply robust accounting to ensure, inter alia, the avoidance of double counting, consistent with guidance adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.
3. The use of internationally transferred mitigation outcomes to achieve nationally determined contributions under this Agreement shall be voluntary and authorized by participating Parties.
4. A mechanism to contribute to the mitigation of greenhouse gas emissions and support sustainable development is hereby established under the authority and guidance of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement for use by Parties on a voluntary basis. It shall be supervised by a body designated by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement, and shall aim:
   (a) To promote the mitigation of greenhouse gas emissions while fostering sustainable development;
   (b) To incentivize and facilitate participation in the mitigation of greenhouse gas emissions by public and private entities authorized by a Party;
   (c) To contribute to the reduction of emission levels in the host Party, which will benefit from mitigation activities resulting in emission reductions that can also be used by another Party to fulfil its nationally determined contribution; and
   (d) To deliver an overall mitigation in global emissions.
5. Emission reductions resulting from the mechanism referred to in paragraph 4 of this Article shall not be used to demonstrate achievement of the host Party's nationally determined contribution if used by another Party to demonstrate achievement of its nationally determined contribution.
6. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall ensure that a share of the proceeds from activities under the mechanism referred to in paragraph 4 of this Article is used to cover administrative expenses as well as to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.
7. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall adopt rules, modalities and procedures for the mechanism referred to in paragraph 4 of this Article at its first session.
8. Parties recognize the importance of integrated, holistic and balanced non-market approaches being available to Parties to assist in the implementation of their nationally determined contributions, in the context of sustainable development and poverty eradication, in a coordinated and effective manner, including through, inter alia, mitigation, adaptation, finance, technology transfer and capacity-building, as appropriate. These approaches shall aim to:
   (a) Promote mitigation and adaptation ambition;
   (b) Enhance public and private sector participation in the implementation of nationally determined contributions; and
   (c) Enable opportunities for coordination across instruments and relevant institutional arrangements.
9. A framework for non-market approaches to sustainable development is hereby defined to promote the non-market approaches referred to in paragraph 8 of this Article.

Article 7

1. Parties hereby establish the global goal on adaptation of enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change, with a view to contributing to sustainable development and ensuring an adequate adaptation response in the context of the temperature goal referred to in Article 2.
2. Parties recognize that adaptation is a global challenge faced by all with local, subnational, national, regional and international dimensions, and that it is a key component of and makes a contribution to the long-term global response to climate change to protect people, livelihoods and ecosystems, taking into account the urgent and immediate needs of those developing country Parties that are particularly vulnerable to the adverse effects of climate change.
3. The adaptation efforts of developing country Parties shall be recognized, in accordance with the modalities to be adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session.
4. Parties recognize that the current need for adaptation is significant and that greater levels of mitigation can reduce the need for additional adaptation efforts, and that greater adaptation needs can involve greater adaptation costs.
5. Parties acknowledge that adaptation action should follow a country-driven, gender-responsive, participatory and fully transparent approach, taking into consideration vulnerable groups, communities and ecosystems, and should be based on and guided by the best available science and, as appropriate, traditional knowledge, knowledge of indigenous peoples and local knowledge systems, with a view to integrating adaptation into relevant socioeconomic and environmental policies and actions, where appropriate.
6. Parties recognize the importance of support for and international cooperation on adaptation efforts and the importance of taking into account the needs of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change.
7. Parties should strengthen their cooperation on enhancing action on adaptation, taking into account the Cancun Adaptation Framework, including with regard to:
   (a) Sharing information, good practices, experiences and lessons learned, including, as appropriate, as these relate to science, planning, policies and implementation in relation to adaptation actions;
   (b) Strengthening institutional arrangements, including those under the Convention that serve this Agreement, to support the synthesis of relevant information and knowledge, and the provision of technical support and guidance to Parties;
   (c) Strengthening scientific knowledge on climate, including research, systematic observation of the climate system and early warning systems, in a manner that informs climate services and supports decision-making;
   (d) Assisting developing country Parties in identifying effective adaptation practices, adaptation needs, priorities, support provided and received for adaptation actions and efforts, and challenges and gaps, in a manner consistent with encouraging good practices;
   (e) Improving the effectiveness and durability of adaptation actions.
8. United Nations specialized organizations and agencies are encouraged to support the efforts of Parties to implement the actions referred to in paragraph 7 of this Article, taking into account the provisions of paragraph 5 of this Article.
9. Each Party shall, as appropriate, engage in adaptation planning processes and the implementation of actions, including the development or enhancement of relevant plans, policies and/or contributions, which may include:
   (a) The implementation of adaptation actions, undertakings and/or efforts;
   (b) The process to formulate and implement national adaptation plans;
   (c) The assessment of climate change impacts and vulnerability, with a view to formulating nationally determined prioritized actions, taking into account vulnerable people, places and ecosystems;
   (d) Monitoring and evaluating and learning from adaptation plans, policies, programmes and actions; and
   (e) Building the resilience of socioeconomic and ecological systems, including through economic diversification and sustainable management of natural resources.

10. Each Party should, as appropriate, submit and update periodically an adaptation communication, which may include its priorities, implementation and support needs, plans and actions, without creating any additional burden for developing country Parties.

11. The adaptation communication referred to in paragraph 10 of this Article shall be, as appropriate, submitted and updated periodically, as a component of or in conjunction with other communications or documents, including a national adaptation plan, a nationally determined contribution as referred to in Article 4, paragraph 2, and/or a national communication.

12. The adaptation communications referred to in paragraph 10 of this Article shall be recorded in a public registry maintained by the secretariat.

13. Continuous and enhanced international support shall be provided to developing country Parties for the implementation of paragraphs 7, 9, 10 and 11 of this Article, in accordance with the provisions of Articles 9, 10 and 11.

14. The global stocktake referred to in Article 14 shall, inter alia:

    (a) Recognize adaptation efforts of developing country Parties;

    (b) Enhance the implementation of adaptation action taking into account the adaptation communication referred to in paragraph 10 of this Article;

    (c) Review the adequacy and effectiveness of adaptation and support provided for adaptation; and

    (d) Review the overall progress made in achieving the global goal on adaptation referred to in paragraph 1 of this Article.

Article 8

1. Parties recognize the importance of averting, minimizing and addressing loss and damage associated with the adverse effects of climate change, including extreme weather events and slow onset events, and the role of sustainable development in reducing the risk of loss and damage.

2. The Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts shall be subject to the authority and guidance of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement and may be enhanced and strengthened, as determined by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

3. Parties should enhance understanding, action and support, including through the Warsaw International Mechanism, as appropriate, on a cooperative and facilitative basis with respect to loss and damage associated with the adverse effects of climate change.

4. Accordingly, areas of cooperation and facilitation to enhance understanding, action and support may include:

    (a) Early warning systems;

    (b) Emergency preparedness;

    (c) Slow onset events;

    (d) Events that may involve irreversible and permanent loss and damage;

    (e) Comprehensive risk assessment and management;

    (f) Risk insurance facilities, climate risk pooling and other insurance solutions;

    (g) Non-economic losses;

    (h) Resilience of communities, livelihoods and ecosystems.

5. The Warsaw International Mechanism shall collaborate with existing bodies and expert groups under the Agreement, as well as relevant organizations and expert bodies outside the Agreement.

Article 9

1. Developed country Parties shall provide financial resources to assist developing country Parties with respect to both mitigation and adaptation in continuation of their existing obligations under the Convention.

2. Other Parties are encouraged to provide or continue to provide such support voluntarily.

3. As part of a global effort, developed country Parties should continue to take the lead in mobilizing climate finance from a wide variety of sources, instruments and channels, noting the significant role of public funds,

through a variety of actions, including supporting country-driven strategies, and taking into account the needs and priorities of developing country Parties. Such mobilization of climate finance should represent a progression beyond previous efforts.

4. The provision of scaled-up financial resources should aim to achieve a balance between adaptation and mitigation, taking into account country-driven strategies, and the priorities and needs of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change and have significant capacity constraints, such as the least developed countries and small island developing States, considering the need for public and grant-based resources for adaptation.

5. Developed country Parties shall biennially communicate indicative quantitative and qualitative information related to paragraphs 1 and 3 of this Article, as applicable, including, as available, projected levels of public financial resources to be provided to developing country Parties. Other Parties providing resources are encouraged to communicate biennially such information on a voluntary basis.

6. The global stocktake referred to in Article 14 shall take into account the relevant information provided by developed country Parties and/or Agreement bodies on efforts related to climate finance.

7. Developed country Parties shall provide transparent and consistent information on support for developing country Parties provided and mobilized through public interventions biennially in accordance with the modalities, procedures and guidelines to be adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement, at its first session, as stipulated in Article 13, paragraph 13. Other Parties are encouraged to do so.

8. The Financial Mechanism of the Convention, including its operating entities, shall serve as the financial mechanism of this Agreement.

9. The institutions serving this Agreement, including the operating entities of the Financial Mechanism of the Convention, shall aim to ensure efficient access to financial resources through simplified approval procedures and enhanced readiness support for developing country Parties, in particular for the least developed countries and small island developing States, in the context of their national climate strategies and plans.

Article 10

1. Parties share a long-term vision on the importance of fully realizing technology development and transfer in order to improve resilience to climate change and to reduce greenhouse gas emissions.

2. Parties, noting the importance of technology for the implementation of mitigation and adaptation actions under this Agreement and recognizing existing technology deployment and dissemination efforts, shall strengthen cooperative action on technology development and transfer.

3. The Technology Mechanism established under the Convention shall serve this Agreement.

4. A technology framework is hereby established to provide overarching guidance to the work of the Technology Mechanism in promoting and facilitating enhanced action on technology development and transfer in order to support the implementation of this Agreement, in pursuit of the long-term vision referred to in paragraph 1 of this Article.

5. Accelerating, encouraging and enabling innovation is critical for an effective, long-term global response to climate change and promoting economic growth and sustainable development. Such effort shall be, as appropriate, supported, including by the Technology Mechanism and, through financial means, by the Financial Mechanism of the Convention, for collaborative approaches to research and development, and facilitating access to technology, in particular for early stages of the technology cycle, to developing country Parties.

6. Support, including financial support, shall be provided to developing country Parties for the implementation of this Article, including for strengthening cooperative action on technology development and transfer at different stages of the technology cycle, with a view to achieving a balance between support for mitigation and adaptation. The global stocktake referred to in Article 14 shall take into account available information on efforts related to support on technology development and transfer for developing country Parties.

Article 11

1. Capacity-building under this Agreement should enhance the capacity and ability of developing country Parties, in particular countries with the least capacity, such as the least developed countries, and those that are particularly vulnerable to the adverse effects of climate change, such as small island developing States, to take

effective climate change action, including, inter alia, to implement adaptation and mitigation actions, and should facilitate technology development, dissemination and deployment, access to climate finance, relevant aspects of education, training and public awareness, and the transparent, timely and accurate communication of information.

2. Capacity-building should be country-driven, based on and responsive to national needs, and foster country ownership of Parties, in particular, for developing country Parties, including at the national, subnational and local levels. Capacity-building should be guided by lessons learned, including those from capacity-building activities under the Convention, and should be an effective, iterative process that is participatory, cross-cutting and gender-responsive.

3. All Parties should cooperate to enhance the capacity of developing country Parties to implement this Agreement. Developed country Parties should enhance support for capacity-building actions in developing country Parties.

4. All Parties enhancing the capacity of developing country Parties to implement this Agreement, including through regional, bilateral and multilateral approaches, shall regularly communicate on these actions or measures on capacity-building. Developing country Parties should regularly communicate progress made on implementing capacity-building plans, policies, actions or measures to implement this Agreement.

5. Capacity-building activities shall be enhanced through appropriate institutional arrangements to support the implementation of this Agreement, including the appropriate institutional arrangements established under the Convention that serve this Agreement. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall, at its first session, consider and adopt a decision on the initial institutional arrangements for capacity-building.

Article 12

Parties shall cooperate in taking measures, as appropriate, to enhance climate change education, training, public awareness, public participation and public access to information, recognizing the importance of these steps with respect to enhancing actions under this Agreement.

Article 13

1. In order to build mutual trust and confidence and to promote effective implementation, an enhanced transparency framework for action and support, with built-in flexibility which takes into account Parties' different capacities and builds upon collective experience is hereby established.

2. The transparency framework shall provide flexibility in the implementation of the provisions of this Article to those developing country Parties that need it in the light of their capacities. The modalities, procedures and guidelines referred to in paragraph 13 of this Article shall reflect such flexibility.

3. The transparency framework shall build on and enhance the transparency arrangements under the Convention, recognizing the special circumstances of the least developed countries and small island developing States, and be implemented in a facilitative, non-intrusive, non-punitive manner, respectful of national sovereignty, and avoid placing undue burden on Parties.

4. The transparency arrangements under the Convention, including national communications, biennial reports and biennial update reports, international assessment and review and international consultation and analysis, shall form part of the experience drawn upon for the development of the modalities, procedures and guidelines under paragraph 13 of this Article.

5. The purpose of the framework for transparency of action is to provide a clear understanding of climate change action in the light of the objective of the Convention as set out in its Article 2, including clarity and tracking of progress towards achieving Parties' individual nationally determined contributions under Article 4, and Parties' adaptation actions under Article 7, including good practices, priorities, needs and gaps, to inform the global stocktake under Article 14.

6. The purpose of the framework for transparency of support is to provide clarity on support provided and received by relevant individual Parties in the context of climate change actions under Articles 4, 7, 9, 10 and 11, and, to the extent possible, to provide a full overview of aggregate financial support provided, to inform the global stocktake under Article 14.

7. Each Party shall regularly provide the following information:

(a) A national inventory report of anthropogenic emissions by sources and removals by sinks of greenhouse gases, prepared using good practice methodologies accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

(b) Information necessary to track progress made in implementing and achieving its nationally determined contribution under Article 4.

8. Each Party should also provide information related to climate change impacts and adaptation under Article 7, as appropriate.

9. Developed country Parties shall, and other Parties that provide support should, provide information on financial, technology transfer and capacity-building support provided to developing country Parties under Article 9, 10 and 11.

10. Developing country Parties should provide information on financial, technology transfer and capacity-building support needed and received under Articles 9, 10 and 11.

11. Information submitted by each Party under paragraphs 7 and 9 of this Article shall undergo a technical expert review, in accordance with decision 1/CP.21. For those developing country Parties that need it in the light of their capacities, the review process shall include assistance in identifying capacity-building needs. In addition, each Party shall participate in a facilitative, multilateral consideration of progress with respect to efforts under Article 9, and its respective implementation and achievement of its nationally determined contribution.

12. The technical expert review under this paragraph shall consist of a consideration of the Party's support provided, as relevant, and its implementation and achievement of its nationally determined contribution. The review shall also identify areas of improvement for the Party, and include a review of the consistency of the information with the modalities, procedures and guidelines referred to in paragraph 13 of this Article, taking into account the flexibility accorded to the Party under paragraph 2 of this Article. The review shall pay particular attention to the respective national capabilities and circumstances of developing country Parties.

13. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall, at its first session, building on experience from the arrangements related to transparency under the Convention, and elaborating on the provisions in this Article, adopt common modalities, procedures and guidelines, as appropriate, for the transparency of action and support.

14. Support shall be provided to developing countries for the implementation of this Article.

15. Support shall also be provided for the building of transparency-related capacity of developing country Parties on a continuous basis.

Article 14

1. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall periodically take stock of the implementation of this Agreement to assess the collective progress towards achieving the purpose of this Agreement and its long-term goals (referred to as the "global stocktake"). It shall do so in a comprehensive and facilitative manner, considering mitigation, adaptation and the means of implementation and support, and in the light of equity and the best available science.

2. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall undertake its first global stocktake in 2023 and every five years thereafter unless otherwise decided by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

3. The outcome of the global stocktake shall inform Parties in updating and enhancing, in a nationally determined manner, their actions and support in accordance with the relevant provisions of this Agreement, as well as in enhancing international cooperation for climate action.

Article 15

1. A mechanism to facilitate implementation of and promote compliance with the provisions of this Agreement is hereby established.

2. The mechanism referred to in paragraph 1 of this Article shall consist of a committee that shall be expert-based and facilitative in nature and function in a manner that is transparent, non-adversarial and non-punitive. The committee shall pay particular attention to the respective national capabilities and circumstances of Parties.

3. The committee shall operate under the modalities and procedures adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session and report annually to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

Article 16

1. The Conference of the Parties, the supreme body of the Convention, shall serve as the meeting of the Parties to this Agreement.
2. Parties to the Convention that are not Parties to this Agreement may participate as observers in the proceedings of any session of the Conference of the Parties serving as the meeting of the Parties to this Agreement. When the Conference of the Parties serves as the meeting of the Parties to this Agreement, decisions under this Agreement shall be taken only by those that are Parties to this Agreement.
3. When the Conference of the Parties serves as the meeting of the Parties to this Agreement, any member of the Bureau of the Conference of the Parties representing a Party to the Convention but, at that time, not a Party to this Agreement, shall be replaced by an additional member to be elected by and from amongst the Parties to this Agreement.
4. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall keep under regular review the implementation of this Agreement and shall make, within its mandate, the decisions necessary to promote its effective implementation. It shall perform the functions assigned to it by this Agreement and shall:
   (a) Establish such subsidiary bodies as deemed necessary for the implementation of this Agreement; and
   (b) Exercise such other functions as may be required for the implementation of this Agreement.
5. The rules of procedure of the Conference of the Parties and the financial procedures applied under the Convention shall be applied mutatis mutandis under this Agreement, except as may be otherwise decided by consensus by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.
6. The first session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall be convened by the secretariat in conjunction with the first session of the Conference of the Parties that is scheduled after the date of entry into force of this Agreement. Subsequent ordinary sessions of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall be held in conjunction with ordinary sessions of the Conference of the Parties, unless otherwise decided by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.
7. Extraordinary sessions of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall be held at such other times as may be deemed necessary by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement or at the written request of any Party, provided that, within six months of the request being communicated to the Parties by the secretariat, it is supported by at least one third of the Parties.
8. The United Nations and its specialized agencies and the International Atomic Energy Agency, as well as any State member thereof or observers thereto not party to the Convention, may be represented at sessions of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement as observers. Any body or agency, whether national or international, governmental or non-governmental, which is qualified in matters covered by this Agreement and which has informed the secretariat of its wish to be represented at a session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement as an observer, may be so admitted unless at least one third of the Parties present object. The admission and participation of observers shall be subject to the rules of procedure referred to in paragraph 5 of this Article.

Article 17

1. The secretariat established by Article 8 of the Convention shall serve as the secretariat of this Agreement.
2. Article 8, paragraph 2, of the Convention on the functions of the secretariat, and Article 8, paragraph 3, of the Convention, on the arrangements made for the functioning of the secretariat, shall apply mutatis mutandis to this Agreement. The secretariat shall, in addition, exercise the functions assigned to it under this Agreement and by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

Article 18

1. The Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation established by Articles 9 and 10 of the Convention shall serve, respectively, as the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Agreement. The provisions of the Convention relating to the functioning of these two bodies shall apply mutatis mutandis to this Agreement. Sessions of the meetings of the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Agreement shall be held in conjunction with the meetings of, respectively, the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of the Convention.
2. Parties to the Convention that are not Parties to this Agreement may participate as observers in the proceedings of any session of the subsidiary bodies. When the subsidiary bodies serve as the subsidiary bodies of this Agreement, decisions under this Agreement shall be taken only by those that are Parties to this Agreement.
3. When the subsidiary bodies established by Articles 9 and 10 of the Convention exercise their functions with regard to matters concerning this Agreement, any member of the bureaux of those subsidiary bodies representing a Party to the Convention but, at that time, not a Party to this Agreement, shall be replaced by an additional member to be elected by and from amongst the Parties to this Agreement.

Article 19

1. Subsidiary bodies or other institutional arrangements established by or under the Convention, other than those referred to in this Agreement, shall serve this Agreement upon a decision of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall specify the functions to be exercised by such subsidiary bodies or arrangements.
2. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement may provide further guidance to such subsidiary bodies and institutional arrangements.

Article 20

1. This Agreement shall be open for signature and subject to ratification, acceptance or approval by States and regional economic integration organizations that are Parties to the Convention. It shall be open for signature at the United Nations Headquarters in New York from 22 April 2016 to 21 April 2017. Thereafter, this Agreement shall be open for accession from the day following the date on which it is closed for signature. Instruments of ratification, acceptance, approval or accession shall be deposited with the Depositary.
2. Any regional economic integration organization that becomes a Party to this Agreement without any of its member States being a Party shall be bound by all the obligations under this Agreement. In the case of regional economic integration organizations with one or more member States that are Parties to this Agreement, the organization and its member States shall decide on their respective responsibilities for the performance of their obligations under this Agreement. In such cases, the organization and the member States shall not be entitled to exercise rights under this Agreement concurrently.
3. In their instruments of ratification, acceptance, approval or accession, regional economic integration organizations shall declare the extent of their competence with respect to the matters governed by this Agreement. These organizations shall also inform the Depositary, who shall in turn inform the Parties, of any substantial modification in the extent of their competence.

Article 21

1. This Agreement shall enter into force on the thirtieth day after the date on which at least 55 Parties to the Convention accounting in total for at least an estimated 55 percent of the total global greenhouse gas emissions have deposited their instruments of ratification, acceptance, approval or accession.
2. Solely for the limited purpose of paragraph 1 of this Article, "total global greenhouse gas emissions" means the most up-to-date amount communicated on or before the date of adoption of this Agreement by the Parties to the Convention.
3. For each State or regional economic integration organization that ratifies, accepts or approves this Agreement or accedes thereto after the conditions set out in paragraph 1 of this Article for entry into force have been fulfilled,

this Agreement shall enter into force on the thirtieth day after the date of deposit by such State or regional economic integration organization of its instrument of ratification, acceptance, approval or accession.

4. For the purposes of paragraph 1 of this Article, any instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by its member States.

Article 22

The provisions of Article 15 of the Convention on the adoption of amendments to the Convention shall apply mutatis mutandis to this Agreement.

Article 23

1. The provisions of Article 16 of the Convention on the adoption and amendment of annexes to the Convention shall apply mutatis mutandis to this Agreement.
2. Annexes to this Agreement shall form an integral part thereof and, unless otherwise expressly provided for, a reference to this Agreement constitutes at the same time a reference to any annexes thereto. Such annexes shall be restricted to lists, forms and any other material of a descriptive nature that is of a scientific, technical, procedural or administrative character.

Article 24

The provisions of Article 14 of the Convention on settlement of disputes shall apply mutatis mutandis to this Agreement.

Article 25

1. Each Party shall have one vote, except as provided for paragraph 2 of this Article.
2. Regional economic integration organizations, in matters within their competence, shall exercise their right to vote with a number of votes equal to the number of their member States that are Parties to this Agreement. Such an organization shall not exercise its right to vote if any of its member States exercises its right, and vice versa.

Article 26

The Secretary-General of the United Nations shall be the Depositary of this Agreement.

Article 27

No reservations may be made to this Agreement.

Article 28

1. At any time after three years from the date on which this Agreement has entered into force for a Party, that Party may withdraw from this Agreement by giving written notification to the Depositary.
2. Any such withdrawal shall take effect upon expiry of one year from the date of receipt by the Depositary of the notification of withdrawal, or on such later date as may be specified in the notification of withdrawal.
3. Any Party that withdraws from the Convention shall be considered as also having withdrawn from this Agreement.

Article 29

The original of this Agreement, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary-General of the United Nations.

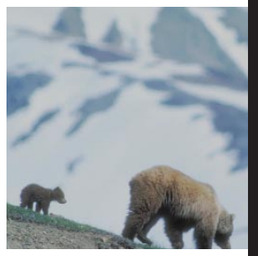
DONE at Paris this twelfth day of December two thousand and fifteen.

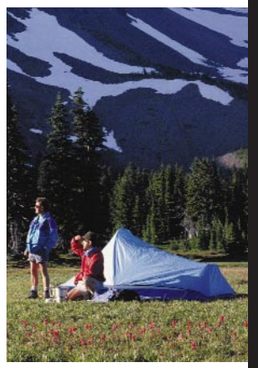
IN WITNESS WHEREOF, the undersigned, being duly authorized to that effect, have signed this Agreement.



CLIMATE CHANGE AND ECOSYSTEMS

Thousands of scientists predict that the earth's climate will change because human activities are altering the chemical composition of the atmosphere through the buildup of greenhouse gases. The heat-trapping property of such gases as carbon dioxide, methane, nitrous oxide, and chloroflurocarbons is undisputed. Greenhouse gases are released into the atmosphere in large quantities by motorized vehicles, utilities, factories, appliances, and landfills.





Although there is uncertainty about exactly how and when the earth's climate will respond to higher concentrations of greenhouse gases, observations indicate that detectable changes are underway. Temperatures will most likely rise by an average of 2 to 6˚F over the next century, along with measurable changes in precipitation, soil moisture, and sea level. All of these changes could have adverse effects on many ecological systems, as well as on human health and the economy.



WHAT CAN YOU DO?

- Inform yourself and others. For more information on climate change and national parks, visit EPA's website at www.epa.gov/globalwarming; and click on "impacts." Or call EPA's National Service Center for Environmental Publications (NSCEP) at 1-800-490-9198 and ask for information on climate change and how it affects wildlife, forestry, and/or sea level rise.
- Encourage more research. If you work for an organization that carries out related scientific studies, suggest including a climate change component to the research.
- Reduce greenhouse gases. Use a more fuel-efficient (or non-motorized) mode of transportation. Carpool. Purchase electronic devices and appliances with the ENERGY STAR® label. Plant trees.

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Policy (2171)
401 M Street, SW
Washington, DC 20460

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EPA

Climate Change and PUBLIC LANDS

National Parks At Risk



CLIMATE CHANGE AND WILDLIFE

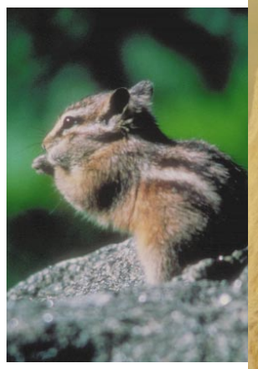
America's national parks were established to preserve valuable natural resources while providing environmentally diverse settings for recreation. They were intended for use by Americans of all generations to come. But these natural treasures may be at risk from global climate change if we do nothing to address the problem. Other public lands, such as national seashores, national forests, wildlife refuges, and Bureau of Land Management lands also could be affected.

Global warming could have numerous impacts on wildlife and their habitat on public lands and the waters that flow through those lands. Many inland freshwater rivers, lakes, and streams may become too warm for the fish and other aquatic species that currently inhabit them.

Climate change also may contribute to a loss of wetlands, beaches, and other habitat. As the oceans warm, the sea level rises and erosion of beaches and wetlands during storms increases. Such national park units as Padre Island, Assateague Island, Fire Island, Cape Hatteras, and Cape Cod could be affected by sea level rise.

States in coastal areas that cannot enact land use planning may find that wetlands and other coastal ecosystems cannot migrate inland as the sea rises. Critical wetlands in wildlife refuges and other public lands could be lost as a result.





CLIMATE CHANGE: PUBLIC LANDS AT RISK

Glacier National Park is located in a pristine mountainous area in northwestern Montana. The park provides habitat for an abundance of wildlife, including the densest population of grizzly bears (a threatened species) in the United States. Climate change could have a serious impact on this national park. Today, the park has approximately 50 glaciers, down from an estimated 150 in 1850. The recession of Sperry Glacier illustrates the impact of recent warming temperatures. If warming trends continue, it is estimated that the park will have no glaciers by 2030. Without glaciers, stream temperatures are expected to rise. Higher water temperatures could affect aquatic ecosystems, especially trout species. Climate change also could alter the types of trees found in the park.

Alaska's pristine ecosystems are especially vulnerable to climate change since warming is projected to be greater at higher latitudes than in other parts of the world. With sufficient increases in temperature, tundra ecosystems are expected to decline significantly. Melting permafrost in Alaska's ruggedly beautiful Denali National Park could jeopardize essential habitats for caribou herds. Melting permafrost also affects freshwater wetland habitats and may lead to increased landslides and erosion. It may clog spawning rivers with silt and trigger the loss of some boreal forests.

Reductions in tundra and related ecosystems also would mean the loss of mammal and migratory waterfowl habitats. In addition, Alaska's native Coho, sockeye, and chinook salmon found in Glacier Bay, Katmai, and Wrangell-St. Elias national parks may be affected by the warming of lakes and rivers.

Saltwater already has intruded 5 miles into **Everglades National Park** from Florida Bay. Increased salinity resulting from sea level rise could damage freshwater ecosystems in the Everglades that provide important habitat for birds, fish, and other wildlife. Freshwater wetlands such as sawgrass, slough, and wet prairie, which are important foraging habitat for wading birds and other wildlife, would decrease in area. These habitat changes could increase pressures on endangered species such as the Florida panther, Key deer, American crocodile, and the Everglades mink.

Without the promise of a stable climate, the history, heritage, wilderness, and beauty preserved by America's public lands are at risk. Climate change could increase the possibility of drought and thus kill the whitebark pines, a source of edible nuts for grizzlies in Yellowstone Park. Fires and flooding also could change the composition of Yellowstone and many other of our nation's celebrated landscapes.





EPA Comment
1-23-3 Region ROMPCS

The Agency agreed to the adopted parameter values used of the panel closure change request to isolate the effects and facilitate a comparison of the proposed panel closure design on the baseline PA and, at the time of the planned changed request, there was uncertainty in the emplacement technique to be used. The Agency would like DOE to address the following comments on several parameters related to panel closures.

1. *Identify and technically justify that ranges of porosity and permeability for the ROM salt PCS during the time period 0 to 100 years (material PCS_T1) are consistent with initial emplacement of the ROM salt without wetting or compaction.*
2. *Provide technical justification for applying a capillary pressure model that assumes zero threshold pressure to region ROMPCS during time periods 100 to 10,000 years (T2 and T3).*
3. *Provide a technical justification for selecting the ranges for the residual brine and gas saturations (SAT_RBRN and SAT_RGAS) during time periods T2 and T3; the justification should include adopting a zero value as the low end.*
4. *Provide technical justification for using the same value for the bulk compressibility of ROM salt during the T1, T2, and T3 time periods (from 0 to 100, 100 to 200, and 200 to 10,000 years).*

DOE Response

The responses to EPA's four comments are as follows:

1. The ranges of porosity and permeability assumed for the run-of-mine (ROM) salt panel closure system (ROMPCS) for use in the PCS-2012 Performance Assessment (PA) were discussed in considerable detail in Camphouse et al. (2012a), as well as the exhaustive discussion of porosity-permeability correlations in the U.S. Department of Energy's (DOE's) response to an EPA comment dated June 7, 2012, regarding the ROMPCS Planned Change Request (DOE 2012). These parameters were agreed to by EPA in an email from Tom Peake to Russ Patterson dated June 19, 2012. As discussed below, these values are consistent with the planned initial emplacement of the ROM salt, and DOE is not aware of any additional information which would give reason to modify them.

   The main component of the ROMPCS at the Waste Isolation Pilot Plant (WIPP) is 100 feet of ROM salt, which will be produced by ongoing mining operations, stored at convenient locations in the mine, and then installed in multiple lifts. Underground testing has demonstrated that front-end loaders and other existing equipment can push the ROM salt against the ribs and back of the panel access drifts, thereby filling the drift (Zimmerly et al. 2012).

   DOE does not intend to establish criteria for the initial condition of the salt pile or to monitor the as-emplaced conditions in the ROM salt. The grain size distribution of the ROM salt, its moisture content, and the degree of initial compaction will not be measured or controlled during installation. It is noted that the ROM salt will contain some moisture from inclusions in the grains and absorbed from humidity in the ventilation air, which may vary depending on the time of year it is emplaced. There are no plans to compact the salt in the pile, although there is expected to be some compaction of lower lifts from the multiple passes of emplacement equipment, such as front-end loaders. In this situation, the initial conditions of the ROM salt are uncertain.

After installation, the ROM salt pile will consolidate due to closure of the panel access drifts. The rate of this consolidation, and hence of the change in porosity and permeability over time, will vary depending on a number of factors. Moisture content may vary depending on the time of year and the varying humidity of the ventilation air. Closure rates of the panel access drifts will vary between panels depending on the local loading conditions and the time that the panel entries have been open before emplacing the salt. These factors add additional uncertainty to the timing of the reconsolidation process for ROM salt in the ROMPCS.

Given these uncertainties, DOE chose an appropriate range of initial porosities for the ROM salt for the PCS-2012 PA. As described in Camphouse et al. (2012a), the range of initial porosity chosen had a minimum of 20% and a maximum of 35%. The maximum initial porosity of 35% is assumed from typical data for unconsolidated granular materials such as sand or gravel (e.g., Bear 1972, Table 2.5.1). The minimum initial porosity of 20% is intended to represent ROM salt with a higher level of moisture content and with some compaction during the emplacement process, and represents a lower bound established using engineering judgment.

As discussed in Camphouse et al. (2012a), the porosity of the ROM salt during the first time period of 0 to 100 years will decrease rapidly due to compaction driven by closure of the entries. A series of JAS3D calculations has been run to estimate the porosity as a function of time for different initial values (Herrick 2012). Given the rapid change in porosity, it was considered reasonable to define the range of porosity for this time period based upon the calculated values at the mid-point, or 50 years. For an assumed initial porosity range of 20% to 35%, the 50-year values calculated by JAS3D are 6.6% to 18.7%. No new data or analyses are available, so there are no reasons to modify this range of values at this time.

The permeability of the ROM salt during the T1 period, from 0 to 100 years, is based on laboratory data for crushed salt cores from WIPP and from the Asse mine in Germany (Camphouse et al. 2012a, Section 5.1.2 and Tables 3 and 4; DOE 2012). The range of permeability during the T1 period is based on the porosity range at the midpoint of the T1 period (50 years) described above of 6.6% to 18.7%. The corresponding range of permeability based on the laboratory data is 1×10^{-12} m^2 to 2×10^{-19} m^2 (Camphouse et al. 2012a, Table 5 for PCS_T1). This range of permeability is consistent with the assumed initial porosity range of the ROM salt, captures the uncertainties in the initial state and reconsolidation process, and is appropriate for performance assessment. No new data are available, so again there is no reason to modify these values at this time.

2. The capillary threshold pressure model used for the PCS-2012 PA is discussed by Camphouse in his June 7 memorandum (2012b). As he explains, values for threshold pressure can be estimated using a best-fit power curve to capillary threshold pressure data for several types of consolidated rock (Vaughn 1996):

$$P_T = (5.6\times10^{-7}\ [\text{MPa}])k^{-0.346}, \quad (1)$$

where P_T is the capillary threshold pressure [MPa] and k is the intrinsic permeability in the x-direction [m^2] (see also Hurtado 1997, Section 3.2.1.1). Equation (1) has been included in the BRAGFLO code since the Compliance Certification Application (CCA) (Vaughn 1996) and provides a dynamic dependence of capillary threshold pressure on permeability. Using this relationship, separate values for the threshold pressure can be set for times T1, T2 and T3 based on their respective sampled values for permeability.

However, as explained in Camphouse (2012b), in BRAGFLO:

> "Instantaneous changes in permeability, due to material changes in a grid region, cause difficulty in numerically satisfying the convergence criterion for the capillary pressure constraint equation. When the convergence criterion cannot be satisfied, the capillary pressure model is disabled for the responsible materials so that a convergent solution can be obtained from BRAGFLO. The flag for this is to set PCT_A = 0, which results in the capillary pressure component to be disabled."

He goes on to note that:

> "BRAGFLO grid regions used to represent the ROM salt panel closures in the PCS-2012 will undergo instantaneous changes in permeability. Specifically, the permeability prescribed to these BRAGFLO grid regions will change instantaneously at 100 and 200 years as closure materials change from PCS_T1 to PCS_T2 and from PCS_T2 to PCS_T3 (Camphouse et al. 2012)."[1]

Because of these numerical issues, the capillary pressure model was disabled in the PCS-2012 PA.

It should be noted that the capillary threshold pressure is not a sensitive parameter for the flow of gases through the ROMPCS for the following reasons:

- In the higher permeability range, from 10^{-16} m^2 to 10^{-18} m^2, capillary threshold pressure calculated from Equation (1) varies between 0.19 MPa (28 psi) and 0.95 MPa (140 psi). These low values of threshold pressure will have minimal impact on hydrologic response because typical repository gas pressures are almost always greater than 0.95 MPa (140 psi). For example, waste panel pressures in the S1, S2, and S4 scenarios are almost always greater than 1 MPa in the performance assessment for CRA-2014 (DOE 2014, Appendix PA-2014, Figures PA-35, PA-50, and PA-56). In this case, setting P_T to zero has no impact on hydrologic response because gas pressure almost always exceeds the threshold pressure and gas can therefore flow into and through the ROM salt.

- In the lower permeability range, from 10^{-19} m^2 to 10^{-22} m^2, the capillary threshold pressure calculated from Equation (1) varies between 2.1 and 23 MPa, and could provide a significant impediment to gas penetrating the ROMPCS. However, hydrologic flow rates for brine or gas through any material with intrinsic permeability less than 10^{-19} m^2 are sufficiently low that the material is essentially impermeable. In this situation, the gas flow through the ROMPCS is insignificant for any value of P_T, and setting P_T to zero has no impact on the hydrologic response.

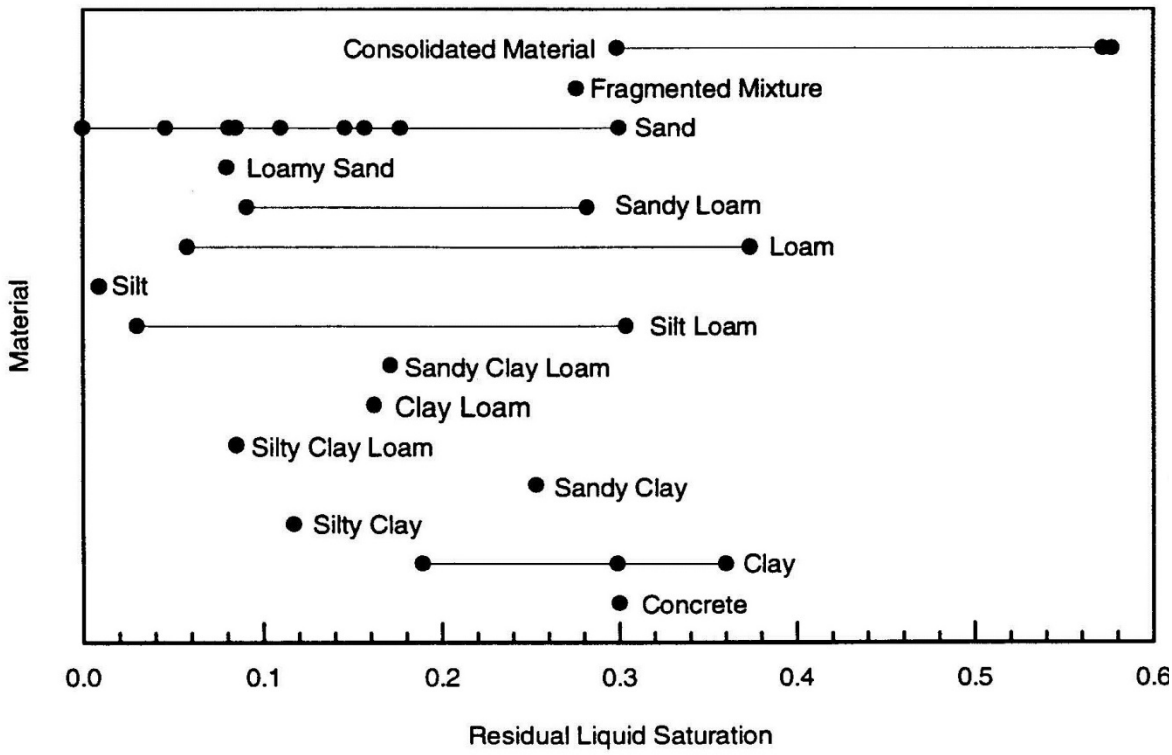
[1] The quoted reference corresponds to Camphouse et al. (2012a) in this response.

3. The residual saturations for brine and gas, which have been used since the CCA when they were established for use in the shaft seals, are based on extensive data from a literature search for geologic materials. The literature search and resulting parameter values are described by Hurtado et al. (1997, Section 3.2.2) and the relevant information is repeated here. It should be noted that calculated repository performance is not sensitive to these parameters, as discussed below.

   Residual liquid saturations for geologic materials were found in four references: Brooks and Corey 1964; Lappala et al. 1987; Parker et al. 1987, and Rawls et al. 1982. Brooks and Corey (1964) determined residual saturations for five unconsolidated samples based on measured values of liquid saturation as a function of capillary pressure. Lappala et al. (1987) determined residual moisture content for 11 soils by obtaining best fits to measured moisture content versus pressure head data using three models. The residual moisture contents from the three models were then averaged and divided by the reported porosity to determine residual liquid saturation for each soil. Parker et al. (1987) fit their saturation-pressure relationship to observed data to obtain residual saturations for a sandy and clayey porous medium. Residual water contents reported by Rawls et al. (1982) for 11 soil texture classes were divided by the reported porosity to obtain residual saturation.

   The values of the residual saturation from the literature search are summarized in graphical form in Figure 1 (from Hurtado et al. 1997, Figure 3-2). All values in Figure 1 fall within the range of 0.0 to 0.6 and all but two values fall within the range of 0.0 to 0.4. Hurtado et al. (1997, Section 3.2.2.2) recommended an expected value of 0.2 and a range of 0.0 to 0.6 for the residual liquid saturation for all shaft seal materials, including crushed salt. For compliance calculations, this has been represented as a cumulative distribution with a minimum value of 0.0, a maximum value of 0.6, and a mode of 0.2 at the 50th percentile (DOE 2004, Appendix PA, Attachment PAR, Parameter 62). This is the recommended distribution for the ROM salt in the ROMPCS and has been used in the PCS-2012 PA and for the CRA-2014 PA. The lower value for this distribution of 0 comes from a "Sandy Porous Media" reported as 0.000 by Parker et al. (1987). The upper bound of 0.6 comes from two samples and could be interpreted as too high since most data fall below 0.4. However, given the natural uncertainties and variation in the residual brine saturation and the fact that PA is not sensitive to it (as discussed next), the value of 0.6 is retained.

   Repository performance is not sensitive to the residual brine saturation or the residual gas saturation of the ROMPCS, as confirmed by the sensitivity study for the CRA-2014 PA (Kirchner 2013). More specifically, PCS_T*i*:SAT_RBRN and PCS_T*i*:SAT_RGAS (*i* = 1, 2, or 3) are not identified as correlated with mean normalized release for Replicates 1, 2, or 3 of the CRA-2014 PA (Kirchner 2013, Tables 6 through 13), with a single exception. The exception is for PCS_T1:SAT_RBRN, which explains 2% of the variability for Culebra releases in Replicate 3 (only) (Kirchner 2013, Table 13). This correlation is not important because it only enters the stepwise ranked regression analysis for one of the three replicates, and because Culebra releases are not significant to overall performance of the repository.



Source: (Hurtado et al. 1997, Figure 3-2)

Figure 1. Distribution of residual liquid saturation values by geologic material

Literature values for residual gas saturation of geologic materials were not found by Hurtado et al. (1997). A single value of 0.18 was found for normal concrete. Given the lack of data, the expected value was set at 0.2 and the recommended range was 0.0 to 0.4 with a uniform distribution. This is the recommended distribution for the ROM salt in the ROMPCS and has been used in the PCS-2012 PA and for the CRA-2014 PA.

4. The recommended value for the bulk compressibility of the ROM salt is 8×10^{-11} Pa^{-1} during the T1 (0-100 years), T2 (100-200 years), and T3 (200-10,000 years) time periods (Camphouse et al. 2012a, Section 5.1.5 and Table 8). It is appropriate to use this value for all time periods because BRAGFLO only uses bulk compressibility to compute changes in storativity due to changes in pore pressure, and those changes are not significant during the T1, T2, or T3 time periods. Changes in porosity due to external loading are calculated separately using fully mechanistic modeling with JAS3D (Herrick 2012). Given this use of the bulk compressibility, the use of a constant value of 8×10^{-11} Pa^{-1} is appropriate because it is representative in all time periods. A more detailed explanation follows.

   The recommended value is based on a nonlinear model relating bulk modulus to fractional density (Hurtado et al. 1997, pages 2-20 and 2-21) that was originally developed by Sjaardema and Krieg (1987):

$$K = Ae^{B\rho}, \\ = (0.0176\,MPa)e^{(14.10\bar{\rho})}, \tag{2}$$

where K is the bulk modulus, $\bar{\rho}$ is the fractional density, and A and B are fitting parameters. The value of 8×10^{-11} Pa^{-1} is appropriate for a porosity of 0.05, or fractional density as defined by Hurtado et al. (1997) (equation 2-10) of 0.956. The porosity of 0.05 corresponds to the mean porosity for ROM salt during the T2 time period and is slightly less than the lower end of the porosity distribution during the T1 time period, and slightly less than the upper end of the porosity distribution for ROM salt during the T3 time period (Camphouse et al. 2012a, Table 2). The resulting value for bulk compressibility of ROM salt is close to the median value for the bulk (rock) compressibility of intact halite, 9.75×10^{-11} Pa^{-1} (DOE 2004, Chapter 6, Table 6-16). A value of 8×10^{-11} Pa^{-1} for the bulk compressibility of ROM salt is therefore appropriate for the T1, T2, and T3 time periods.

Throughout the regulatory period of 10,000 years, the ROM salt porosity used by BRAGFLO in the three time periods is obtained by sampling a porosity range developed from JAS3D mechanical calculations, which are used to predict the time-dependent compaction of the ROM salt as a function of initial porosity. This process is discussed in Camphouse (2012a) and is noted in the answer to the first question. As noted in Camphouse (2012a), the porosity ranges sampled will vary by time period. During T1 the range is 6.6% to 18.7%, during T2 2.5% to 7.5%, and during T3 0.1% to 5.19%.

Bulk compressibility in BRAGFLO, and its related value of pore volume compressibility, is used to account for porosity changes due to pore pressure changes in the halite surrounding the waste rooms, and thus changes in storativity. The bulk compressibility is defined by Freeze and Cherry (1979, page 54):

$$c = -\frac{1}{V_T}\frac{dV_T}{d\sigma_e}, \tag{3}$$

where c is the compressibility, V_T is the total volume of the medium, and σ_e is the effective stress.

The BRAGFLO code uses a modified form of Equation (3) to define porosity changes in a porous medium:

$$\frac{\phi}{\phi_0} = exp\left[\frac{c_r}{\phi_0}(p - p_0)\right]. \tag{4}$$

where ϕ is porosity [unitless], p is the brine pressure in the pores [Pa], c_r is the bulk compressibility [Pa^{-1}], and the subscript 0 denotes initial conditions (DOE 2014, Appendix PA-2014, Equations (PA.30) and (PA.37)). This formulation is appropriate for the halite around the waste panels, where changes in the external confining stress will be minimal, so the only significant change in effective stress comes from changes in pore pressures.

For the ROM salt in the panel closure both the external loading and the pore pressures will change as a function of time, so Equation (4) will have a time-varying effect on the porosity. However, it can be shown that this effect is extremely small. During the T1 time period, the numerical values for the parameters in Equation (4) are as follows:

- The pore pressure, p, is set to its maximum value, 7×10^5 Pa, during the T1 time period.
- The initial pore pressure, p_0, is set to atmospheric pressure, 1.01×10^5 Pa.
- The rock or bulk compressibility, c_r, is equal to 8×10^{-11} Pa^{-1}, as discussed above.

Table 1 presents the calculated changes in porosity where the initial porosity, ϕ_0, is 0.20, 0.25, 0.30, or 0.35 (Camphouse et al. 2012a, Table 1).

Table 1. Porosity changes predicted by Equation (3) during the T1 time period

ϕ_0	0.20	0.25	0.30	0.35
$\frac{\phi}{\phi_0}$	1.00024	1.00019	1.00016	1.00014
% change	0.024%	0.019%	0.016%	0.014%

The results in Table 1 demonstrate that the porosity changes in time T1 induced by pore compressibility are less than 0.03% of the initial porosity for all initial conditions. This conclusion is also valid during the T2 and T3 time periods. For example, using the bulk compressibility of 8×10^{-11} Pa^{-1}, the mean porosity for time T2 of 0.05, and a maximum pore pressure of 14 MPa, the porosity change induced by pore compressibility is around 1.8% of the initial porosity.

These calculated porosity changes are minimal compared to the changes built into the assumed porosity ranges from the JAS3D calculations, so it follows that the porosity changes computed from bulk compressibility are not significant during the T1, T2, or T3 time periods, and the use of a constant value for rock compressibility of 8×10^{-11} Pa^{-1} is appropriate for compliance calculations.

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[2] Brooks and Corey (1964) was submitted to EPA as a reference for Appendix BRAGFLO of the CCA.
*Copyrighted reference not provided in Enclosure 2.

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[*]Copyrighted reference not provided in Enclosure 2.

[3]Parker et al. (1987) was submitted to EPA as a reference for Appendix C, Fluid Flow Analysis, which is part of Appendix SEAL of the CCA.

EPA Comment
1-23-4 Region DRZ_PCS

The Agency would like DOE to address the following comments related to the parameter values adopted for the DRZ_PCS:

1. *Provide technical justification for assigning the same sampled value of porosity to the material in DRZ_PCS region for both early and late time periods (T2 and T3) when the DRZ is undergoing consolidation and healing.*
2. *Provide technical justification for the apparent discrepancy created by independently sampling the permeability of material DRZ_PCS, representing a healed DRZ, from a distribution that can provide a sampled permeability as much as seven orders of magnitude higher than the permeability of intact halite.*
3. *Provide technical justifications for assigning zero values to the residual brine and gas saturations (SAT_RBRN and SAT_RGAS) in CRA-2014 for the region DRZ_PCS during the T3 time period (200 to 10,000 years).*
4. *Provide technical justification for applying a capillary pressure model that assumes zero threshold pressure in region DRZ_PCS during the T3 time period (200 to 10,000 years).*
5. *Provide technical justification for the value of the bulk compressibility of the DRZ_PCS region, and applying that same value during both early and late time periods (T2 and T3) when the material in that region is undergoing consolidation.*

DOE Response

The various items in this comment refer to the region in the BRAGFLO grid identified as DRZ_PCS, primarily during the T2 and T3 time periods (100-200 years and >200 years). The DRZ_PCS corresponds to the areas above and below the panel closures where the surrounding halite has been disturbed during mining, but where, as external stress is applied due to consolidation of the ROMPCS, the disturbance, and hence the porosity will be healed. Strictly speaking, the region identified as DRZ_PCS is only differentiated in the BRAGFLO grid for the T3 period; for the T1 and T2 periods the regions representing the DRZ_PCS have properties that are identical with the DRZ around the waste panels. Figures MASS-7, MASS-8, and MASS-9 (DOE 2014, Appendix MASS-2014), reproduced below, illustrate the evolution of the DRZ_PCS regions during the T1, T2, and T3 time periods, respectively. In the following response, the nomenclature "DRZ_PCS" will be used more loosely to refer to the DRZ above and below the panel closures during any of the time periods.

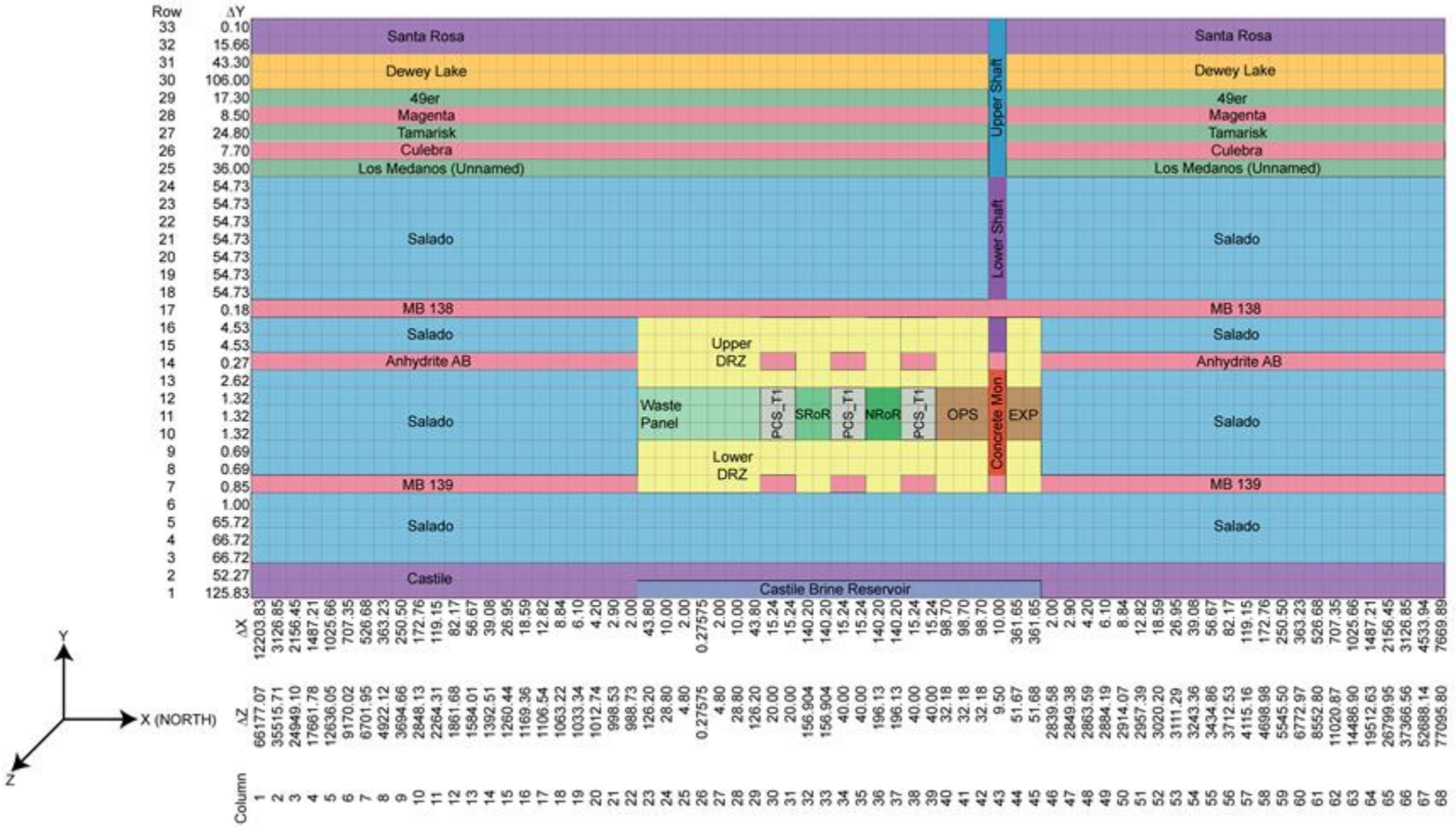


Figure MASS-7. CRA-2014 PA BRAGFLO grid and material map, years 0 to 100

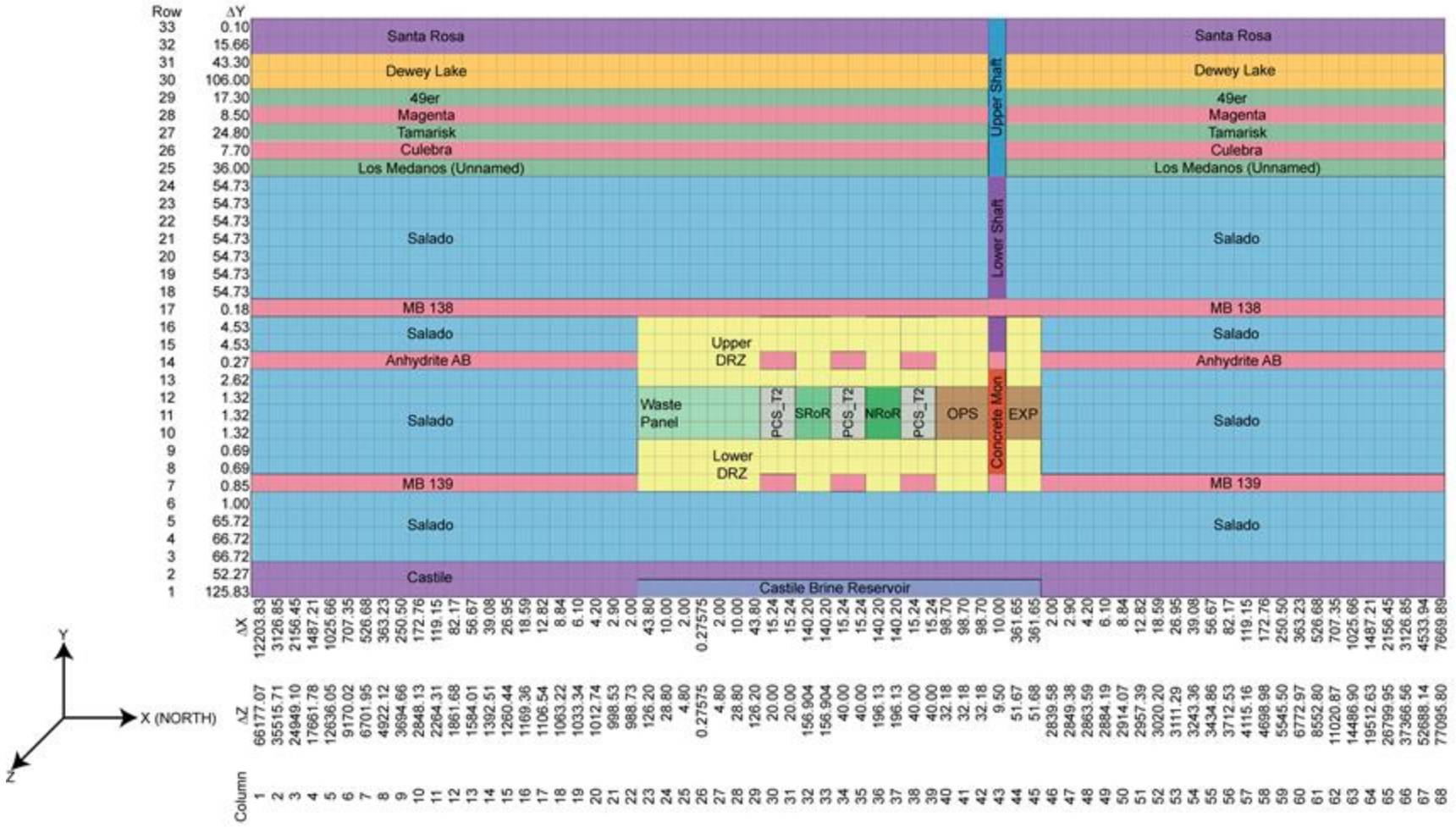


Figure MASS-8. CRA-2014 PA BRAGFLO grid and material map, years 100 to 200

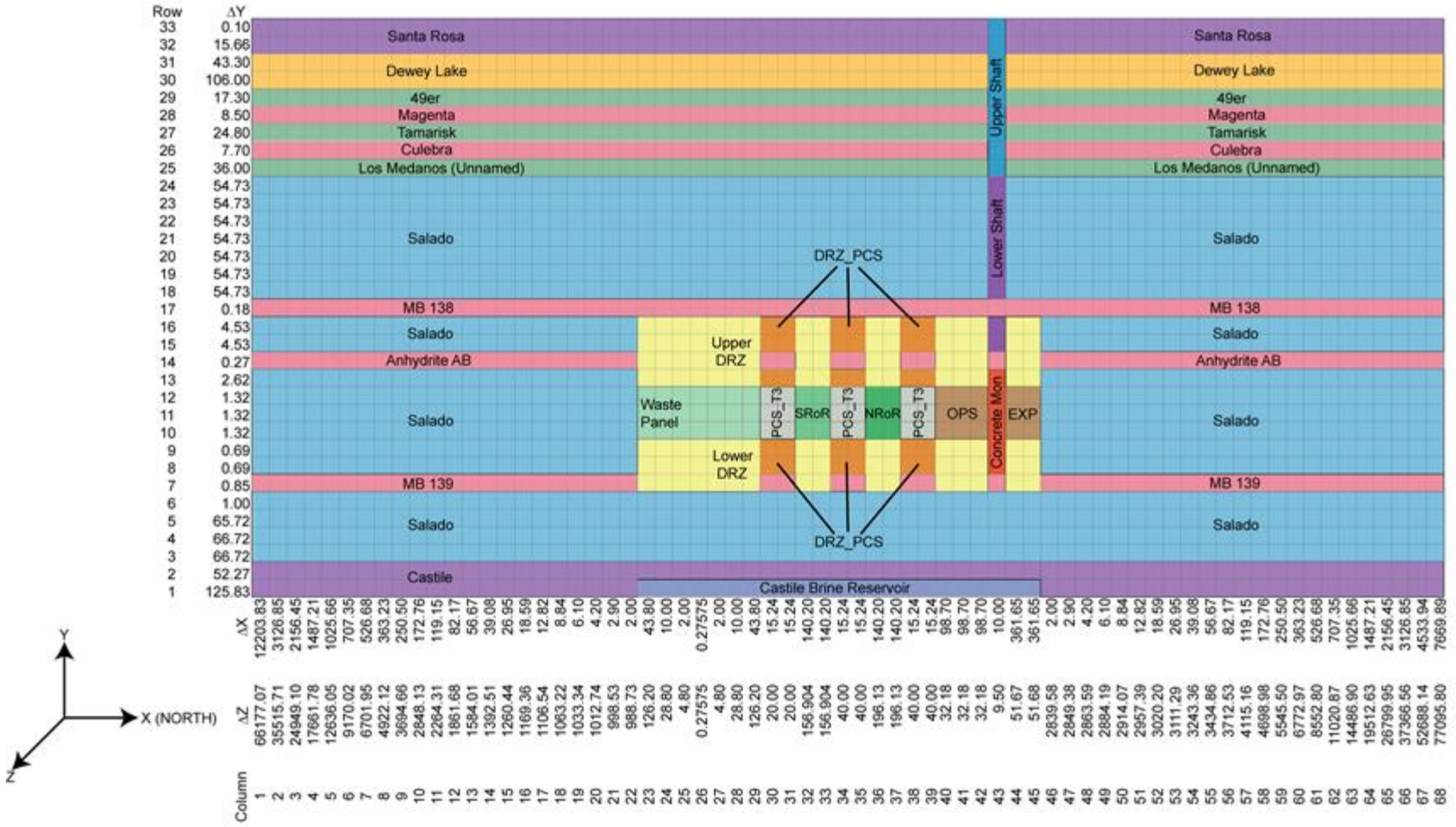


Figure MASS-9. CRA-2014 PA BRAGFLO grid and material map, years 200 to time of intrusion

The responses to EPA's five comments are as follows:

1. The DRZ_PCS region covers the area above and below the panel closure where the surrounding halite has been disturbed during mining, but where, as external stress is applied due to consolidation of the ROMPCS, the disturbance, and hence the porosity will be healed. The porosity of the DRZ around the waste emplacement area is calculated from the porosity of the intact halite, which is sampled from a range of 0.1% to 5.19% (Ismail 2007). The DRZ porosity is calculated by adding 0.0029 to the sampled value of porosity for intact halite (Vaughn 1996a). The value 0.0029 was determined prior to the Compliance Certification Application (CCA) as the difference between the median value of intact halite porosity and the median DRZ porosity value obtained from the Q-Room experiments (Christian-Frear 1996).

   During times T1 and T2, before the DRZ_PCS is fully loaded due to consolidation of the ROMPCS, the porosity of the DRZ_PCS regions are equal to the porosity of the DRZ surrounding the waste emplacement areas. During time T3, while it is recognized that the DRZ will have experienced some healing due to consolidation of the ROMPCS, the porosity is kept unchanged for two primary reasons:

   - There is considerable uncertainty in the porosity values for intact halite and for the DRZ, which are available from laboratory and in situ testing. With an assumed range of halite porosity of 0.1% to 5.19%, the value of the DRZ porosity has a range of 0.39% to 5.48% (Ismail 2007). This range adequately covers the likely porosity both before and after full load is applied to the DRZ (i.e., for times T1, T2 and T3).

   - The results of PA calculations are not sensitive to the porosities of the DRZ and DRZ_PCS within their given ranges. Both of these values are derived from the sampled value of intact halite porosity, as noted above, by adding a constant value of 0.0029. The sensitivity study for the CRA-2014 PA (Kirchner 2013) indicates that for total mean normalized release, the intact halite porosity contributes 1% of the variability in Replicates 1 and 2 and 3% of the variability in Replicate 3 (Kirchner 2013, Tables 6 and 7). Since the DRZ porosity is calculated from this sampled value, an identical result also holds for the DRZ porosity. In addition, the porosity of the DRZ_PCS during the T1, T2, or T3 time periods is not within the top 8 sensitive parameters for Replicates 1, 2, or 3 for mean total normalized release (Kirchner 2013, Tables 6 and 7). In this situation, creating and using a time-dependent model for porosity of the DRZ or the DRZ_PCS adds no value to the assessment of long-term repository performance.

2. Initially, it is assumed that the DRZ around the PCS will be no different from that around the disposal rooms since there will be only a small back stress from the consolidating ROM salt in the ROMPCS. Geomechanical calculations for closure of panel entries and consolidation of the ROM salt predict that the back stress from the ROM salt does not become appreciable until approximately 200 years after the ROM salt is emplaced (Herrick 2012, Section 5.2). While the back stress is low, the state of the DRZ surrounding the PCS will be similar to the state of the DRZ surrounding the disposal rooms, and the values of porosity and permeability of the DRZ_PCS during the T1 (0 to 100 years) and T2 (100 to 200 years) time periods have been set equal to those for the disposal room DRZ. The permeability of the DRZ_PCS therefore has a range of $10^{-12.5}$ m^2 to $10^{-19.4}$ m^2 for the first 200 years after repository closure. Further details are provided in Camphouse et al. (2012a, Section 5.2.1).

   At 200 years (the start of the T3 time period), back stress builds up to values between 6 and 10 MPa, and fractures in the DRZ above the ROMPCS should begin to heal; by 500 years the back

stress reaches about 12 MPa (Camphouse et al. 2012a, Figures 9 and 10 and discussion on pages 21 and 22). The recommended range of permeability for the DRZ_PCS is 2×10^{-21} m^2 to 1×10^{-17} m^2 during the T3 time period. This recommendation is based on permeability measurements for cores of crushed salt and the range represents the uncertainty in the degree and timing of reconsolidation in the DRZ_PCS. This range is significantly greater than the permeability range for intact halite, which is 10^{-24} m^2 to 10^{-21} m^2, for the following reasons:

- As noted above, the DRZ begins to heal when the back stress builds up to 6 to 10 MPa after 200 years. However, the timing for complete healing of the DRZ is uncertain. The JAS3D calculations predict that the back stress approaches 12 MPa by 500 years (Herrick 2012, Figures 9 through 13) and may slowly increase to full lithostatic stress, approximately 14 MPa, thereafter. Full healing of the DRZ may require thousands of years to approach the extremely low permeability of intact salt. There is no discrepancy if the DRZ, even after some healing, has a permeability somewhat higher than the very low values for intact halite strata that have been undisturbed for millions of years.

- Given the uncertainty in the timing of the healing process, PA represents a range of flow rates through the DRZ_PCS. At the high end of the permeability range, 1×10^{-17} m^2, the permeability of the DRZ_PCS is similar to that of concrete. At the low end of the permeability range, 2×10^{-21} m^2, the DRZ_PCS is essentially impermeable (i.e., no flow) and similar to the intact salt. This approach provides an appropriate range of hydrologic responses for the DRZ_PCS, thereby capturing the uncertainty in the timing of the healing process for performance assessment.

  An alternative to this approach is to use the permeability range for intact halite for the DRZ during T3. This is not appropriate because DOE does not have data or analyses to prove that the DRZ fully heals by 200 years.

- Independent analytic work by EPA has shown that mean total normalized releases are insensitive to the range of DRZ_PCS permeability during the T3 time period. EPA performed an independent PA using a revised permeability range for the DRZ_PCS of 1×10^{-22} m^2 to 1×10^{-20} m^2 during the T3 time period (Economy 2013). The results of the EPA's independent PA demonstrated that mean total normalized releases are essentially equal for the EPA's or the DOE's distributions for DRZ_PCS permeability in the PCS-2012 PA (Economy 2014).

3. The residual saturations for brine and gas, which have been used since the CCA when they were established for use in the shaft seals, are based on extensive data from a literature search for geologic materials. The literature search and resulting parameter values are described by Hurtado et al. (1997, Section 3.2.2) and included in the answer to item #3 of our response to Comment 1-23-3, and are not repeated here.

   All values from this literature search fall within the range of 0.0 to 0.6, and all but two values fall within the range of 0.0 to 0.4. For compliance calculations, this has been represented as a cumulative distribution with a minimum value of 0.0, a maximum value of 0.6, and a mode of 0.2 at the 50th percentile (DOE 2004, Appendix PA, Attachment PAR, Parameter 62). This is the recommended distribution for the DRZ_PCS during T1, T2, and T3, and has been used in the PCS-2012 PA and for the CRA-2014 PA.

   The lower value for this distribution of 0 comes from a "Sandy Porous Media" reported as 0.000 by Parker et al. (1987), and is the lower bound of the distribution, rather than a fixed value used

in the calculations. It should be noted that repository performance is not sensitive to the residual brine saturation or the residual gas saturation of the DRZ_PCS during T3, as confirmed by an independent PA performed by the EPA. The EPA chose a residual brine saturation of 0.1 and a residual gas saturation of 0.05 for the DRZ_PCS during T3 (Economy 2014, Table 1) and compared the results to those from the PCS-2014 PA (Camphouse 2012a, Table 11). The results of the EPA's independent PA demonstrated that mean total normalized releases are essentially equal for the EPA's values or the DOE's values of residual saturation in the DRZ_PCS (Economy 2014, Figure 4).

4. The capillary threshold pressure model used for the PCS-2012 PA is discussed by Camphouse in his June 7 memorandum (Camphouse 2012b). As he explains, values for threshold pressure can be estimated using a best-fit power curve to capillary threshold pressure data for several types of consolidated rock (Vaughn 1996b):

$$P_T = (5.6\times10^{-7}\ [\text{MPa}])k^{-0.346}, \quad (1)$$

where P_T is the capillary threshold pressure [MPa] and k is the intrinsic permeability in the x-direction [m^2] (see also Hurtado 1997, Section 3.2.1.1). Equation (1) has been included in the BRAGFLO code since the CCA (Vaughn 1996b) and provides a dynamic dependence of capillary threshold pressure on permeability. Using this relationship, separate values for the threshold pressure can be set for times T1, T2 and T3 based on their respective sampled values for permeability.

However, as explained in Camphouse (2012b), in BRAGFLO:

> "Instantaneous changes in permeability, due to material changes in a grid region, cause difficulty in numerically satisfying the convergence criterion for the capillary pressure constraint equation. When the convergence criterion cannot be satisfied, the capillary pressure model is disabled for the responsible materials so that a convergent solution can be obtained from BRAGFLO. The flag for this is to set PCT_A = 0, which results in the capillary pressure component to be disabled."

He goes on to note that:

> "BRAGFLO grid regions used to represent the ROM salt panel closures in the PCS-2012 will undergo instantaneous changes in permeability. Specifically, the permeability prescribed to these BRAGFLO grid regions will change instantaneously at 100 and 200 years as closure materials change from PCS_T1 to PCS_T2 and from PCS_T2 to PCS_T3 (Camphouse et al. 2012)."[1]

Because of these numerical issues, the capillary pressure model was disabled in the PCS-2012 PA and in the CRA-2014 PA.

It should be noted that the capillary threshold pressure is not a sensitive parameter for the flow of gases through the DRZ_PCS for the following reasons:

- In the higher DRZ_PCS permeability range, from 10^{-18} m^2 to 10^{-17} m^2, capillary threshold pressure calculated from Equation (1) varies between 0.19 MPa (28 psi) and 0.95 MPa

[1] The quoted reference corresponds to Camphouse et al. (2012a) in this response.

(140 psi). These low values of threshold pressure will have minimal impact on hydrologic response because typical repository gas pressures are almost always greater than 0.95 MPa (140 psi). For example, waste panel pressures in the S1, S2, and S4 scenarios are almost always greater than 1 MPa in the performance assessment for CRA-2014 (DOE 2014, Appendix PA-2014, Figures PA-35, PA-50, and PA-56). In this case, setting P_T to zero has no significant impact on the hydrologic response because gas pressure almost always exceeds the threshold pressure and gas can therefore flow into and through the DRZ_PCS.

- In the lower permeability range, from 10^{-21} m^2 to 10^{-19} m^2, the capillary threshold pressure calculated from Equation (1) varies between 2.1 and 23 MPa, and could provide a significant impediment to gas penetrating the DRZ_PCS. However, hydrologic flow rates for brine or gas through any material with intrinsic permeability less than 10^{-19} m^2 are sufficiently low that the material is essentially impermeable. In this situation, the gas flow through the DRZ_PCS is insignificant for any value of P_T, and setting P_T to zero has no impact on the hydrologic response.

5. The recommended value for the bulk (or rock) compressibility of the DRZ_PCS is 7.41×10^{-10} Pa^{-1} during the T1 (0-100 years), T2 (100-200 years), and T3 (200-10,000 years) time periods (DOE 2004, Appendix PA, Attachment PAR, Table PAR-33). This value has been used since the CCA as noted by Vaughn (1996a), and this bulk compressibility is only used to determine changes in storativity in BRAGFLO.

   The permeability of the DRZ_PCS is the dominant parameter in determining flow through the DRZ_PCS, not changes in storativity; therefore, since permeability is not affected by compressibility effects, the use of a constant value for compressibility is appropriate. Any minor changes in porosity from bulk compressibility will not have a significant impact on hydrological response of the DRZ_PCS. A more detailed explanation follows.

   Bulk compressibility in BRAGFLO, and its related value of pore volume compressibility, is used to account for porosity changes due to pore pressures changes in the halite surrounding the waste rooms, and thus changes in storativity. The bulk compressibility is defined by Freeze and Cherry (1979, page 54):

$$c = -\frac{1}{V_T}\frac{dV_T}{d\sigma_e}, \tag{2}$$

   where c is the compressibility, V_T is the total volume of the medium, and σ_e is the effective stress.

   The BRAGFLO code uses a modified form of Equation (2) to define porosity changes in a porous medium:

$$\frac{\phi}{\phi_0} = exp\left[\frac{c_r}{\phi_0}(p - p_0)\right]. \tag{3}$$

   where ϕ is porosity [unitless], p is the brine pressure in the pores [Pa], c_r is the bulk compressibility [Pa^{-1}], and the subscript 0 denotes initial conditions (DOE 2009, Appendix PA-2009, Equations (PA.30) and (PA.37)). For the DRZ surrounding the panel closure both the external loading and the pore pressures will change as a function of time, so Equation (3) will

have a time varying effect on the porosity. However, it can easily be shown that this effect is extremely small.

Table 1 presents the calculated changes in porosity during the T2 and T3 time periods for the bulk compressibility of 7.41×10^{-10} Pa^{-1} and a maximum pore pressure of 14 MPa, and starting porosities covering the range calculated from the intact halite range. The magnitude of the porosity changes for initial porosities equal to or greater than 0.01 is less than 0.02 and will not have a significant impact on the hydrologic response of the repository. This is clear by considering the volume of the DRZ_PCS above and below a panel closure in Figure MASS-9 (DOE 2014, Appendix MASS-2014; see the fourth page in this response). The DRZ_PCS region has an orange color in Figure MASS-9. The combined volume above and below the ROM PCS between the south rest-of-repository and the north rest-of-repository is:

$$V_{DRZ_PCS} = (0.69+0.69+2.62+4.53+4.53)(15.48+15.48)(40+40) = 31{,}850 \text{ m}^3. \quad (4)$$

The porosity change for $\phi_0 = 0.01$ is 0.018 (see Table 1) and the corresponding increase in free volume is (31,850 m^3)(0.018) = 570 m^3. This increase is not significant for the overall volumes of brine and gas in the repository, and will not be important for repository performance. For example, the total excavated volume of the repository is 436,000 m^3 (SNL 1992, Section 3.1.1) and the approximate volume of a single panel is (0.1)(436,000 m^3) = 43,600 m^3, which is much greater than the pore volume change in the DRZ_PCS.

Table 1. Porosity changes predicted by Equation (3) during the T2 and T3 time periods

ϕ_0	0.0548	0.03	0.01	0.0038
$\frac{\phi}{\phi_0}$	1.207	1.410	2.801	15.05
$\Delta\phi = \phi - \phi_0$	0.011	0.012	0.018	0.053

For the minimum initial porosity of 0.0038, the maximum change in porosity is 0.053 and the corresponding volume increase is (31,850 m^3)(0.053) = 1,700 m^3. Again, this increase is not significant for the overall volumes of brine and gas in the repository, and will not be important for repository performance.

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*Copyrighted reference not provided in Enclosure 2.

[2]Parker et al. (1987) was previously submitted to EPA as a reference for Appendix C, Fluid Flow Analysis, which is part of Appendix SEAL of the CCA.

EPA Comment

1-23-6 Probability of Encountering a Castile Brine Pocket. *Please address the following comments:*

1. *TDEM results are site specific and indicate the presence of potentially large volumes of brine beneath some waste panels. Explain why TDEM data is not used in DOE's proposed approach for estimating PBRINE.*
2. *DOE's approach ignored the presence of high electrical conductivity zones identified beneath four of the ten WIPP waste panels. Please explain how this omission affected the comparison of the TDEM approach with DOE's newly derived drilling data approach.*
3. *ERMS 558724 asserts that brine encounters of sufficient size to impact the repository would be noticed and logged by a driller. The approach does not acknowledge the potential of encountering a low yield and high volume brine pocket which would not be noticed by the driller in calculating PBRINE. Please address the basis for not considering the low yield, high volume brine pockets.*
4. *DOE reported the same count of 34 brine intrusions out of 678 Castile wells in 2008. It is unclear whether 2008 was the last time a brine intrusion was observed at the time of collecting data for the CRA-2014 or if 2008 was the cut-off date for recoding a brine intrusion. Please clarify.*
5. *The circular regions in Figure 5 of ERMS 558724 were selected to include a known brine pocket encounter. Please provide information as to whether this radius would bias the results and the sensitivity of the results to the radius size.*
6. *Provide information as to how the well depths, for each well that did and did not encounter a brine pocket, were incorporated into the drilling data analysis.*
7. *The ratios in Table 2 of ERMS 558724 include double-counting of many wells. Please provide information as to how this affected the results.*
8. *ERMS 558724 states that pressurized brine is associated with near-vertical fractures. However, WIPP-12 yielded large volumes of brine that is assumed to have been stored and transmitted through the extensive and primarily interconnected horizontal to sub-horizontal fractures. Please provide an explanation as to how the near-vertical fracture model adopted by DOE's modified PBRINE parameter is consistent with evidence that WIPP-12 releases are attributed to horizontal and sub-horizontal fractures.*

DOE Response

1. The goal in estimating parameters for use in the WIPP PA is, to the extent feasible, to provide the best estimate of the parameter based on empirical evidence and to represent the uncertainty on those estimates by assigning a distribution to the parameter. The form and magnitude of dispersion represented by the distribution ideally could be determined from the empirical data, but in practice, additional sources of uncertainty must be considered as, for example, when the empirical data are few or not entirely representative of the site in question. In some cases uncertainties on parameters can be ignored, as when the parameter has little influence on the result or when the uncertainty is negligible. In some cases parameters must be estimated by expert elicitation, drawing on the experience of knowledgeable experts to subjectively define a distribution for a parameter. Since the goal in risk assessment generally is to minimize the chance of a false-negative conclusion, parameters deemed low-influence or well-known can be assigned conservative (risk maximizing) values with no uncertainty. In a probabilistic risk assessment, like that employed in WIPP PA, the use of conservative assumption for parameters must be weighed carefully since excessive conservatism will transform the results from the best estimates with uncertainties that capture the possible range of outcomes, to conservative estimates with uncertainties that likely range into regions of highly improbable or impossible outcomes. In addition, implausible predictions from a probabilistic model can cast doubt on its overall credibility.

This update of the probability of encountering a pressurized brine pocket (PBRINE) is consistent with the requirement in 40 CFR 194.15(a)(2), which states that recertification applications include "…all additional monitoring data, analysis, and results." The monitoring data collected by the Delaware Basin Drilling Surveillance Program (DBDSP) show a dramatic increase in drilling activity over the last 10 years, with no additional occurrences of pressurized brine within the monitoring area. The DOE believes that these new data should be recognized and incorporated as appropriate into the CRA-2014, and that the distribution derived from these data is more credible than the distribution previously derived using time-domain electromagnetic (TDEM) data (Peake 1998). It will be shown below that:

- the distribution developed from the time-domain electromagnetic data is based on questionable assumptions,
- the assignment of a uniform distribution to introduce conservatism is questionable on theoretical grounds,
- the uniform distribution is a poor representation of the results from a Monte Carlo-based analysis conducted by the EPA, and
- the subjectively assigned uniform distribution could be less conservative than a more realistic distribution based on statistical theory.

Thus the previous uniform distribution of PBRINE mandated by EPA both impacts the credibility of the results and impairs their interpretation within the probabilistic framework of the compliance assessment. The distribution used in the CRA-2014 is based on a direct measurement of the frequency of brine encounters, is consistent with the probabilistic framework of compliance assessment, and does not require the use of a conceptual model having many uncertainties to derive the probability of encountering brine from the measurements. Furthermore, a subset of the well data from the region was used to estimate PBRINE. These data came from a reference region near WIPP that was selected because it had a higher than average rate of brine encounters. Thus, the nominal estimate of PBRINE used in the CRA-2014 is at least twice as large as the regional rate and more than three times the rate encountered in wells around the WIPP site. In addition, the shape of the CRA-2014 distribution is derived from statistical theory and reduces the weight associated with low-probability events. Based on these features, the DOE considers the CRA-2014 distribution to be the more defensible alternative. This conclusion is derived from review of:

- The data on pressurized brine around the WIPP site
- The on-site drilling data
- The TDEM data and their interpretation
- The theoretical expectation for the form of the distribution
- Assumptions made in the stochastic simulation of depths
- Using drilling data to estimate PBRINE

Pressurized brine in the region of the WIPP

The occurrence of pressurized brine in the Castile formation was known at the time that the DOE was evaluating sites for the WIPP. The potential for encountering pressurized brine became an issue during the site suitability investigation process when a brine release occurred from the WIPP-12 test well (Popielak et al. 1983). Of three wells drilled within the WIPP boundary, only WIPP-12 encountered pressurized brine. The parameter PBRINE is potentially influential because it is the influx of brine into the repository that can cause gas pressures to rise and subsequently give rise to releases of contaminated brine to the surface. Thus, it is a parameter that one would want to estimate as accurately as possible with an appropriate level of uncertainty. However, the actual sensitivity of direct brine releases (DBR) to PBRINE is quite low (Fig. 1), as documented in Kirchner (2013). Here DBR was only weakly correlated with PBRINE (contributing about 2% to the variability) in one of three replicates. This is undoubtedly because it takes only one drilling event where pressurized brine is encountered to flood the repository, so additional intrusions into pressurized brine have little or no impact. We observed an average of 7.44 drilling intrusions per future in the CRA-2014 simulations. This value is stored in an output file from the CCDFGF code, but for verification the expected value can be computed as

$$7.43 = 0.00673 \text{ intrusions-km}^{-2}\text{-yr}^{-1} \times 0.1115 \text{ km}^2 \times 9900 \text{ yr}$$

where the area of 0.1115 km^2 is the footprint of the repository and 9900 is the number of years simulated after the period of institutional controls. Thus, low values of PBRINE can result in no brine pockets being penetrated in a future. For example, if PBRINE is 0.01, then the probability of seeing at least 1 brine encounter in 7 trials is only about 0.07. If PBRINE is 0.6, that probability is nearly 1 (0.998). This nonlinear response means that the impact of the change in the distribution cannot be judged merely by comparing the ranges of the old and new distribution. It also means that the shape of the distribution, particularly the weight in the lower tail, is important.

Herein we explain why we are more confident in the distribution of PBRINE developed from the drilling data than we are in the distribution derived from the TDEM data. Our lack of confidence in the TDEM-derived distribution arises from:

- The lack of any data that could be used to correlate TDEM data with the probability of encountering brine
- The assumption that the proportion of the area of the repository underlain by regions of high conductivity is a good estimate of the probability of encountering brine
- The assumption that the error bar on TDEM depth of ±75 m was one sigma
- The discounting of expert opinion that brine pockets would be contained within the anhydrite
- The use of a uniform distribution that ignores both the results obtained from stochastic simulation of uncertainties in the depth estimates and the expected distribution for a Bernoulli process

Each of these observations is explained in the following text.

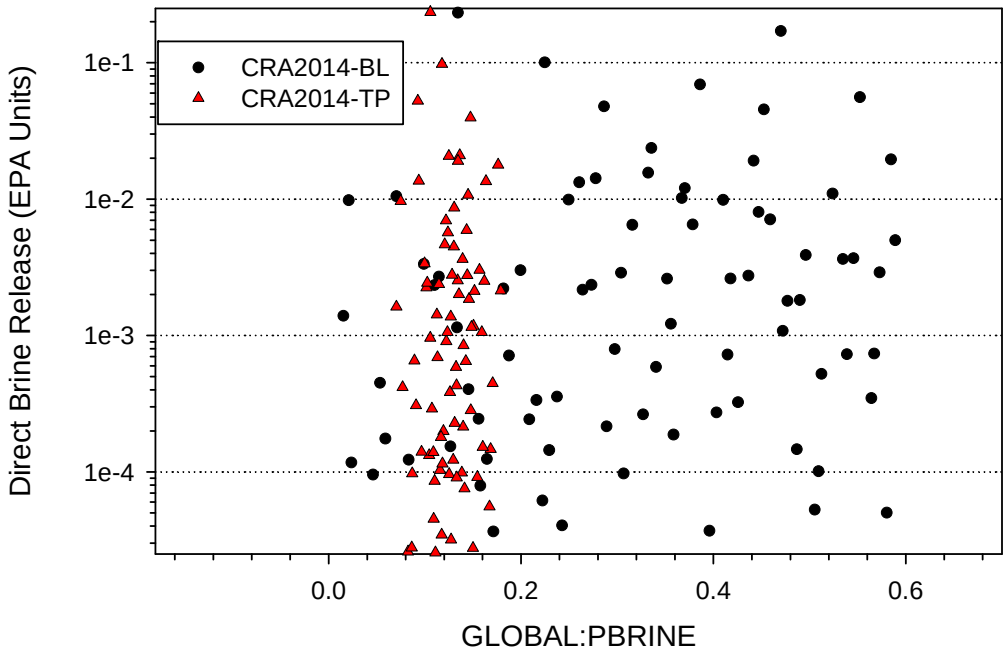


Figure 2. Scatter plot of rank direct brine release vs. rank PBRINE for CRA2014-BL and CRA2014-TP

The on-site drilling data, TDEM data and flaws in their interpretation

Given the limitation that direct measurement of the probability of encountering brine in a drilling event over the WIPP repository cannot be made, one might consider alternative methods for estimating this probability. An ideal experiment would be to find a non-intrusive measurement that could be used to predict the rate of pressurized brine encounters, make those measurements over the repository, then calibrate the non-intrusive measurements to the probability of encountering pressurized brine on a similar off-site area where both the non-intrusive measurements and drilling experiments could be conducted. However, this was not an experiment that was conducted. What is available are data from non-intrusive TDEM measurements over the repository, data from three wells drilled on the WIPP site and well logs from commercial drilling operations in the area surrounding the WIPP site. The TDEM measurements can be used to provide a map of regions of high conductivity, which are likely associated with the presence of water. The TDEM data can be interpreted to estimate the depth of the high-conductivity regions. Thus, the TDEM data were valuable in alerting DOE to the possibility of there being pressurized brine pockets beneath the WIPP repository. The TDEM data are also valuable in that they detected no areas of high conductivity at depths of less than 1000 m (The Earth Technology Corporation 1988). However, TDEM results provide a two-dimensional map of areas of high conductivity and cannot be used to estimate the volume of brine, particularly at the low levels of resolution that result from the requirement of obtaining measurements at the depth of the Castile. Thus, the portion of the question that asserts that "the TDEM results … indicate the presence of potentially large volumes of brine" is not accurate.

In order to make measurements to the depth of the Castile, the TDEM loop had to be a square with the length of the side about equal to the depth of interest. The TDEM loops in this case were 500 m

by 500 m on a side (The Earth Technologies Corporation 1988). This large size also reduced noise in early time channels as compared to smaller sized loops (The Earth Technologies Corporation 1988). Thus, these are necessarily low-resolution data and they cannot provide a detailed map of brine pockets, which are expected to have cross-sectional areas considerably smaller than 500 m by 500 m, nor can TDEM data distinguish pressurized from non-pressurized fluids. Expert opinion is that water contained wholly within the anhydrite layers of the Castile formation is likely to be pressurized brine, whereas water within the Bell Canyon formation, which permits lateral flow, is unlikely to be pressurized (Peake 1998; Sandia 1992 page 5-4; Powers et al. 1996; Powers et al. 1978). The conceptual model for the brine pockets is that they were formed within near-vertical cracks in the anhydrite of the Castile formation during periods of deformation (Popielak et al. 1983). Borns (1983) confirmed the near-vertical orientation of brine-producing fractures through study of core from the WIPP-12 borehole. Popielak et al. (1983) found no evidence of hydraulic or chemical connection between reservoirs, but did conclude that low permeability microfractures around the large fractures contained the majority of the brine. Evidence for the lack of connectivity between reservoirs (Popielak et al. 1983) includes:

- Hydraulic heads that are substantially different between reservoirs
- The containment of gas by the reservoirs
- Different brine and gas chemistries among the reservoirs
- Geographic separation and heterogeneity in the spatial distribution of reservoirs
- Bulk chemical equilibria between brine, gas and reservoir rock

This conceptual model provides the foundation for making assumptions to translate the TDEM-generated map of conductivity into the probability of encountering pressurized brine. In particular, it suggests that it is wrong to assume that any well drilled in an area identified by TDEM as being an area of high conductivity will necessarily encounter pressurized brine. However, it is probably fair to say that a well drilled in an area where TDEM showed no areas of high conductivity within the Castile is highly unlikely to encounter a brine reservoir.

There are two sets of site-specific data: TDEM data showing areas of high conductivity and data from three drilling events. The distribution of PBRINE used in the previous CRAs was derived from the TDEM data with no consideration of the rates of encounters of pressurized brine pockets observed either on the WIPP site or in the area surrounding WIPP. The translation from TDEM measurements to a probability of encountering brine relied on stochastic modelling of the uncertainties in the TDEM data and formation depths, and some conservative assumptions about the interpretation of the TDEM data (Peake 1998). An important consideration in this stochastic modeling was the assumption about the location of pressurized brine in the Castile. Two possibilities were considered: that the pressurized brine was contained within the anhydrite, so the base of Anhydrite III was the lower bound of depth, or that the pressurized brine could extend to the base of the Castile. Both limits were used in the analysis and each produced a distribution. These distributions were widely separated from each other, having ranges of about 0.02 to 0.06 (base of Anhydrite III) and 0.35-0.58 (base of Castile) based on Fig. 5-5 in Peake (1998). A bimodal composite distribution was suggested in Peake (1998) that combined the two distributions by assuming each was equally likely (Peake 1998, Fig. 5-5). The stochastic modeling also considered the limiting cases of 1) there being no spatial correlations between areas associated with high TDEM conductivity measurements and 2) there being very high correlation between such areas. These two cases were labeled the random model and the block model, where the block model derived its name from the spatial aggregation of areas surrounding each of 36

measurement points with the aggregate being assigned the measurement value, thus yielding 36 blocks of elevations. The block model was considered to be more conservative than the random model. The block model was chosen to represent the data even though the TDEM measurements showed no indication of spatial correlation.

Peake (1998) notes that "… the TDEM results do not account for the possibility of obliquely oriented or oblong-shaped brine pockets…". Thus, the areas mapped out using the TDEM data do not represent areas of high probability of encountering a pressurized brine pocket but rather areas of high conductivity in the Castile formation defined at a very low level of spatial resolution. There are no data available to use to translate from drilling in an area of high conductivity to the probability of encountering pressurized brine, so this important correlation was treated as being perfect, i.e., having a coefficient of 1, in spite of the core data that suggest brine resides in nearly vertical cracks. In 1997, the EPA mandated that the parameter PBRINE be assigned a uniform distribution over the range 0.01 to 0.60. The uniform distribution was selected under the assumption that there were no data on which to base an expected or modal value and the end points were set subjectively, with the upper end primarily based on an interpretation of the TDEM data. This uniform distribution was based on the stochastic modeling of the depth of the TDEM conductive layers but ignored the suggestion that a bimodal distribution be used. As a result, the uniform distribution assigns non-zero probability to values of PBRINE between 0.08 and 0.35 in spite of the lack of any sampled data in this range from the stochastic analysis. Furthermore, the equal weighting given to each distribution does not appear to be justified by the opinions of the experts (Popielak et al. 1983) that pressurized brine would be found primarily, and probably exclusively, in the anhydrite layers.

The other site-specific data are the drilling data from three wells, one of which encountered pressurized brine. EPA has previously argued that the WIPP site's geology with respect to the abundance of brine pockets could be different from that of neighboring areas, based in part on this one encounter with pressurized brine. These data are too sparse to derive a correlation between TDEM results and the probability of encountering brine. However, encountering pressurized brine reservoirs can be assumed to be a Bernoulli process because for each drilling event the probability of encountering pressurized brine can be assumed to be independent of previous drilling events. A 90% confidence interval on the observed rate of encountering pressurized brine on the WIPP site, 0.33, is approximately 0.02 to 0.86 (Hahn and Meeker 1991). This interval represents the range of PBRINE that, with 90% confidence, could give rise to *exactly* 1 out of 3 brine encounters. In Kirchner et al. (2012) we showed that the range of PBRINE that could give rise to *at least* one brine encounter in three trials to be 0.02 to 0.63, thus showing that the observed rate of encounters within the WIPP boundary was not inconsistent with the average rate of encounters in the vicinity of WIPP.

Conservatism of the uniform distribution

The TDEM-based interval has a lower maximum than the observation-based estimate based on the three on-site wells, but the uniform distribution has a higher frequency of the lowest values as compared to the distribution expected for a Bernoulli process based on data from only three wells (Fig. 2). In other words, the distribution derived from the TDEM data and a set of assumptions could well be less conservative than a distribution based on the site-specific drilling data in spite of the uniform distribution's smaller range because of the greater influence of low values than high values. However, basing an estimate of PBRINE on data from only three wells obviously introduces both a coarseness and a high degree of uncertainty on the value; the only possible estimates of PBRINE that can be obtained from three trials are 0, 1/3, 2/3 and 1. Furthermore, a rate of 33% far exceeds the rate of encounters of pressurized brine in the area surrounding WIPP. Thus, these data were also judged to be inadequate for providing a creditable estimate of PBRINE.

Flaws in the stochastic simulation of uncertainty in depth measurements

A study of the TDEM analysis report (Peake 1998) also raised questions about the methodology used to map areas of high conductivity under the various panels. The method employed a stochastic simulation model to try to incorporate the measurement uncertainty, ± 75 m, into the assessment. This uncertainty was sampled and applied to the nominal depth measurement values, and then the sampled depths were compared to the extent of the Castile to assess whether they could be included or excluded as indicators of potential Castile brine pockets. One major concern was the interpretation of the measurement uncertainty as representing one sigma. Normally, a measurement uncertainty expressed using ± is assumed to represent an absolute limit or two standard deviations (sigma) unless specifically noted to be an estimate of dispersion with a specific "coverage factor" (the multiplier on sigma) (Taylor and Kuyatt 1994; ANSI 1997). The Earth Technology Corporation (1988) stated that "…the accuracy of determining depth to brine in this survey was , ± 75 m," thus lending credence to the interpretation that ± 75 m represented an absolute interval and not a measure of variability or dispersion. Furthermore, -75 m and +75 m are explicitly labelled the "minimum depth" and the "maximum depth" on the TDEM depth estimates in Borns (1996). If sigma was reduced, then the area of regions of high conductivity within the Castile would probably be reduced as well. Presumably, the assignment of areas possibly containing brine pockets to panels where the nominal value did not indicate brine was related to this interpretation of uncertainty. However, there were insufficient details in the report to reproduce this analysis with the interpretation of the measurement error as being two-sigma.

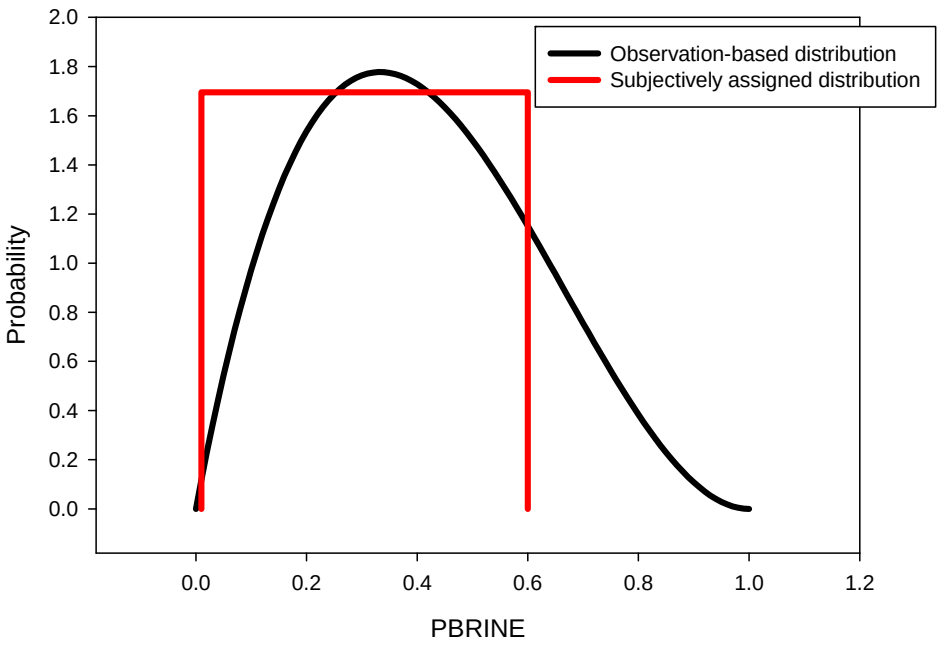


Figure 3. Previous uniform distribution based on a subjective analysis of the TDEM data and the distribution of uncertainty based on encountering pressurized brine once in three trials

Estimating PBRINE based on the drilling data

Given the subsequent increase in the number of commercial wells in the area surrounding WIPP and based on the number of encounters of pressurized brine recorded in the well logs for those wells, DOE's position is that the uniform distribution assigned to PBRINE and used prior to the CRA-2014 fails to properly characterize the probability of encountering brine. On one hand, a rate of 60% of wells encountering brine far exceeds the observed rate of brine encounters in the region, even within an area where the frequency of encountering brine is high compared to the average rate across the region surrounding WIPP (Kirchner et al. 2012). On the other hand, a nominal probability of 0.01 for encounters seems low given the drilling data now available. Furthermore, the drilling data provide information that can be used to define a "most likely" value to use as the mode of a unimodal distribution to replace the uniform distribution, hence reducing the weight in the tails of the distribution.

One advantage of using the drilling data over the TDEM data is that the drilling data do not require any consideration of the distribution and geometry of pressurized brine pockets. There are only two assumptions that need to be made about the data: 1) the drilling logs identify encounters of pressurized brine pockets having characteristics like those modeled in BRAGFLO, and 2) the area from which the data are tabulated has an equivalent or higher density of pressurized brine pockets as compared to the area under the repository. Having a higher density of brine pockets would lead to a conservative estimate of PBRINE. It is our opinion that the commercial drilling data are consistent with both of these assumptions. Thus, the drilling data from commercial wells in the vicinity of WIPP were judged to give direct measurements for the probability of encountering brine, thus eliminating many of the uncertainties and unknowns associated with deriving PBRINE from the TDEM data. Arguments in favor of these assumptions were addressed in Kirchner et al. (2012), but will be reiterated and expanded upon herein.

There was an early concern as to whether the frequency of brine pocket intrusions in the region around the WIPP site was a suitable estimate for the WIPP site in particular. Powers et al. (1996) addressed that concern by doing an extensive geostatistical analysis on the drilling data available at that time. They looked for spatial autocorrelations in the data and correlations with factors such as the thickness of the formations. Powers et al. (1996) concluded that the probability of encountering pressurized brine under the waste panels was 0.08, with no estimate of uncertainty on that value. In Kirchner et al. (2012) we selected an area that would maximize the observed rate of brine encounters to ameliorate concern about using non-site-specific data. Furthermore, we constructed a confidence interval for the estimate of the true probability based on the observed frequency drawing upon statistical theory for Bernoulli processes. What we did not do explicitly in that report was to compare the rate from the reference area to the rate observed on and in a band around the WIPP site. That comparison follows.

The number of wells on which to base PBRINE can be expanded from the three on the site by using wells near the WIPP boundary. For example, using the most recent data on wells within a square having borders about 2.5 miles from the WIPP boundary extends the number of wells to 517 (Fig. 3). Of these, 18 encountered pressurized brine, giving a value of PBRINE of 0.035, or 3.5%. This is lower than the ratio for the region currently used, which is about 5%. However, restrictions on drilling imposed by the state to protect potash resources result in some areas near the WIPP showing few or no wells. For that reason we chose to reduce the chance of estimating a rate of brine encounters that is lower than that which might be encountered on the WIPP site by analyzing a sub-region to the northeast of the WIPP (Kirchner et al. 2012). This area showed a rate of brine encounters of 12.7% and the distribution employed in CRA-2014 was derived using that rate and the theory of Bernoulli processes (Kirchner et al. 2012). Thus, the nominal estimate of PBRINE used in the CRA-2014 is at

least twice as large as the regional rate and more than three times the rate encountered in wells around the WIPP site. We believe that this conservatism, in addition to the uncertainty associated with that value, should encompass any tendency to underreport brine encounters.

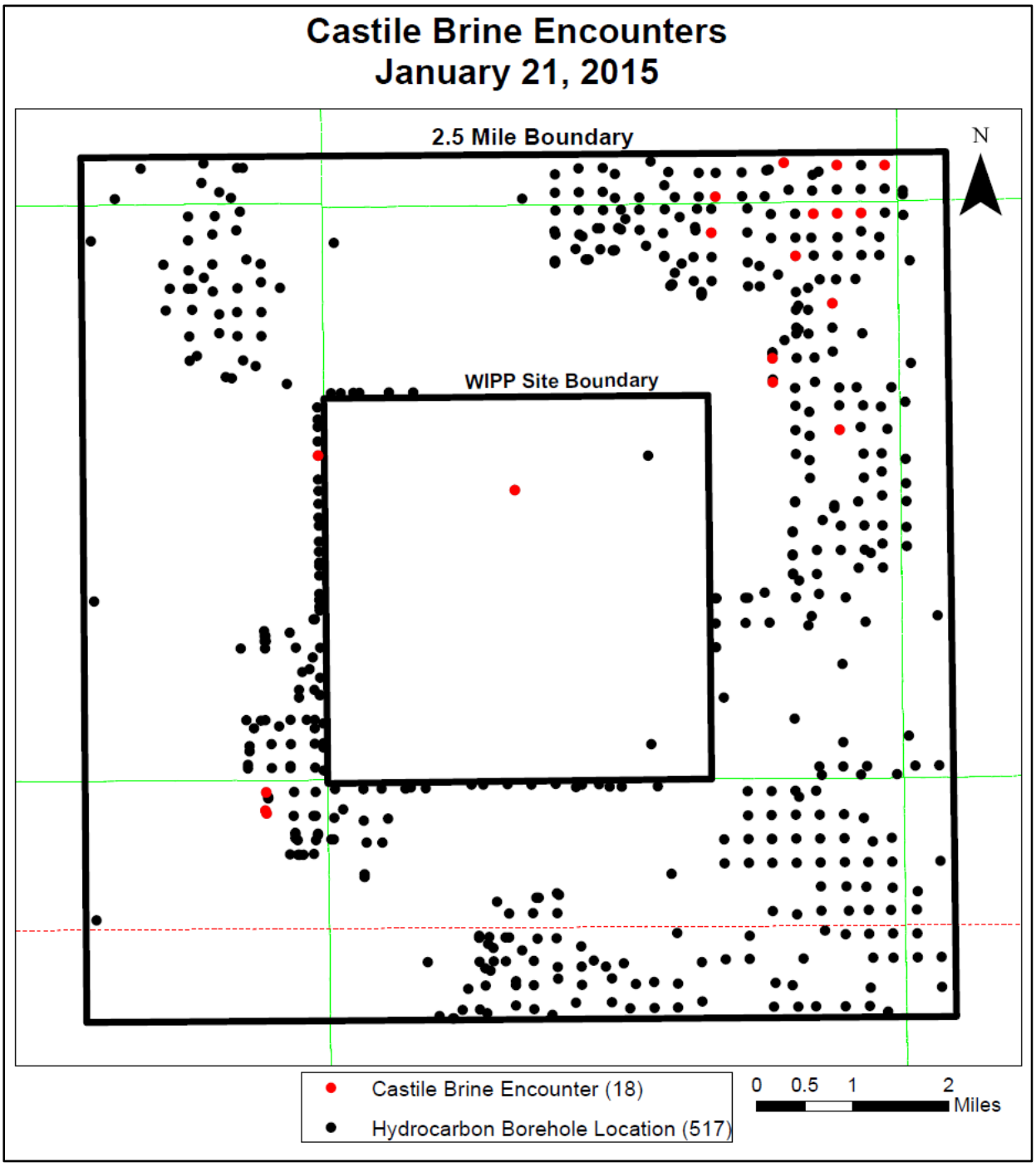


Figure 4. Wells in close vicinity to WIPP

To summarize:

- The TDEM data only provide a low-resolution, 2-dimensional map of the depth to regions of high conductivity
- The site-specific well data are too sparse to develop a correlation between TDEM results and the probability of encountering brine
- There are no TDEM data in the areas surrounding WIPP to use to derive a correlation between encountering brine and being in a TDEM-identified zone of high conductivity in the Castile
- The assumption that the proportion of the area of the repository underlain by regions of high conductivity ignores the near vertical orientation of the brine reservoirs, and thus overestimates the correlation between encountering brine and being in a TDEM-identified zone of high conductivity in the Castile
- The stochastic analysis, which expanded the proportion of the area of the repository underlain by regions of high conductivity, assumed that the error bar on TDEM depth of ±75 m was one sigma, whereas it should have been assumed to be two sigma
- The composite bimodal distribution derived from the analysis assumed equal weighting for using the base of the anhydrite and the base of the Castile, in spite of the expert opinion that brine pockets would be contained within the anhydrite
- The uniform distribution derived from the analysis assigned probabilities to values of PBRINE not represented in the results of the stochastic sampling, which yielded a bimodal distribution
- The uniform distribution has more mass in the left tail than would a modal distribution, like a normal distribution, and hence is less conservative than such a distribution would be.
- The drilling data, in contrast to the TDEM data, provide a direct measurement of the rate of encountering brine that does not depend on a conceptual model for brine reservoirs
- The drilling data, although not site-specific, were selected from an area showing 2 to 3 times the rate of encounters of brine as compared to the area immediately surrounding the WIPP site, thus providing conservatism
- The distribution of uncertainty on PBRINE estimated from the drilling data can be derived from the theory of Bernoulli processes, and thus is totally objective

EPA has previously argued that the WIPP site's geology with respect to the abundance of brine pockets could be different from that of neighboring areas, based in part on having an encounter with pressurized brine in one of three wells drilled on the site. We have shown that this observed rate has an uncertainty, based on statistical theory, which encompasses the much lower rate of brine encounters in the region. In the absence of evidence to the contrary, we have no reason to believe that the probability of encountering brine on the WIPP site would be greater than that observed in neighboring regions and expect it to be considerably lower than that observed in the reference area chosen for our derivation of PBRINE. Given this evaluation, we concluded that 1) the TDEM data method for estimating PBRINE was less credible than the method involving use of the commercial drilling data, and 2) we could see no way that the TDEM data could contribute to improving the estimate of PBRINE based on the drilling data.

2. This comment appears to be about Kirchner et al. (2012), where we attempted to estimate a conditional probability of encountering brine given that a well was in an area identified by TDEM as having a zone of high conductivity within the Castile. To be clear, that part of the analysis has nothing to do with our approach in deriving a new distribution for PBRINE. The reinterpretation of the TDEM data was done simply to make the distributions directly comparable, since in our opinion the calculation of the previous estimate of PBRINE failed to incorporate a reasonable assumption for the conditional probability, and hence was the probability of being in an area of high conductivity rather than the probability of encountering brine. Omitting four of the ten panels in our assessment was an error, based on a misinterpretation of the text, and including them and their estimates of TDEM areas would expand the TDEM-derived distribution to the right and also affect the shape of the distribution. However, the Kirchner et al. (2012) analysis also ignored the potential error in interpreting measurement uncertainty (the interpretation of ±75 m) since there was no way given the available information to reproduce the stochastic analysis with which the panel-specific areas were derived. Because the position of the maximum value of the distribution is expected to have little influence on releases, as discussed under comment 1, including the area estimates for the four panels when properly deriving the TDEM-based distribution would have little impact of a practical nature and would not improve the credibility of the TDEM-derived distribution.

3. A low-yield, high-volume brine pocket originating from the Castile is not consistent with our understanding of the characteristics of this formation. Ductile rock units behave plastically and exert pressures upon any resident liquids at or approaching lithostatic for that unit (Beauheim and Roberts 2002). Therefore low-yield (read: low-pressure) brine flows from this unit are not observed or reported from drillers in the area. That is, in the rare instances when brine is encountered from the Castile, it is always found to be at high pressure. In our opinion the conservatisms in our mean rate (a factor of 2-3 larger than the observed rate around the WIPP site) and the uncertainty on that rate should encompass any likely truncation of the detection rate of brine pockets.

4. Although there was a significant increase in the number of wells drilled in the region since 2008, none of the new wells encountered brine. The last brine occurrence recorded was in 2004; therefore, the count remains at 34.

5. To be clear, the neighborhood analysis of drilling events with and without brine encounters was not used in the development of the distribution of PBRINE in the CRA-2014. The purpose of that analysis was to try to derive a conditional probability for being in an area having brine pockets and actually encountering brine. The radius of 500 m was shown to maximize the average ratio between wells with brine encounters to wells without encounters. It was stated in Kirchner et al. (2012) "Although the 1000 m diameter of the circles is somewhat arbitrary, examination of Fig. 5 shows that increasing the diameter will most likely add more wells without brine intrusions than wells with intrusions, and thus drive the average ratio lower. Circles of a smaller diameter would result in many more cases of there being only a single well contained and thus be inadequate for estimating the ratio. Finally, smaller circles would not reflect minimum well spacing requirements for drilling in the Delaware Basin, and would exclude effectively all neighboring wells." To specifically answer this question, the selection of the radius would have a profound impact on the analysis of the conditional probability for the TDEM data, but we are not advocating using the neighborhood analysis to rectify problems with the TDEM data. In our opinion combining the TDEM data with this crude estimate of the conditional probability linking TDEM areas to the probability of encountering brine would not improve the credibility of the resulting distribution given some of the other issues discussed in comment 1.

6. The DBDSP researches the well files of new wells drilled in the New Mexico portion of the Delaware Basin each year looking for instances of encounters with pressurized brine. The program also sends

out an annual survey to operators of new wells asking if they encountered pressurized brine during the drilling process. Because stratigraphy changes over the survey area, the depth of brine intercept is not as important as the formation in which brine is encountered. Therefore, the specific depths of brine intercepts are not incorporated into the analysis. It is also recognized by industry experience that pressurized brine flows rarely originate from units deeper than the Castile in the WIPP vicinity. Consistent with this, all brine flows reported by area drillers originate from the Castile Formation. Therefore, only Castile brine occurrences are counted by the DBDSP, and only these were used in the data analysis. The wells that did not encounter pressurized brine were all deep boreholes that transcend the Castile to the deeper oil and gas producing zones.

7. To be clear, the neighborhood analysis of drilling events with and without brine encounters was not used in the development of the distribution of PBRINE in the CRA-2014. Table 2 of Kirchner et al. (2012) provides data on the frequency of encountering brine in another intrusion within 500 m of a known brine intrusion. The assumption is that the drilling/encounter events are independent. The fact that a well having a brine intrusion is near two or more wells also having brine intrusions, hence being counted twice or more, has no impact on the estimated frequencies. Indeed, if there were strong spatial correlations in the locations of wells encountering brine, the existence of multiple neighbors having brine would be expected. The motive behind this neighborhood analysis was to try to convert the previous TDEM distribution into one that was a better estimate of PBRINE because it included a more realistic value for the correlation between PBRINE and TDEM-identified areas of high conductivity. However, given the flaws in the TDEM analysis addressed in comment 1 and the large uncertainty associated with the estimate of correlation, we do not see this approach as a viable way to improve the credibility of the estimate of PBRINE based on the TDEM data.

8. With regard to the EPA's assertion that WIPP-12 brine is assumed to have been transmitted via horizontal to sub-horizontal fractures, we respectfully request the source of this information, as it directly conflicts with information and analyses presented in Popeilak et al. (1983) and Borns (1983), which are the primary sources of Castile brine characterization. We are not aware of any characterization data that conflict or refute the current understanding that brine in the Castile is within near-vertical, high-angle fractures.

   However, the modified distribution for PBRINE is based on a direct observation of the rate of brine encounters and does not depend on a conceptual model of the orientation of brine pockets nor the presence of horizontal or sub-horizontal fractures. PBRINE is not related to the volume of brine encountered, it is just the probability of encountering brine by wells drilled through the Castile. Indeed, one advantage of using the drilling data is that these data are used to measure PBRINE based on whatever the system of fractures is, rather than a model of what those fractures are likely to be.

   We have not attempted to alter the conceptual model for pressurized brine within performance assessment, although many of the assumptions used in the pressurized brine conceptual model are quite conservative, and could benefit from more realism. However, changes of this nature (conceptual model changes) go beyond what we understand to be allowable through the recertification process. Therefore, we have attempted to stay within the content constraints for recertification applications, and have limited changes to an update of the parameter PBRINE. This parameter update is based on our obligation to comply with 40 CFR 194.15(a)(2), where it states that recertification applications include "…all additional monitoring data, analysis, and results." The monitoring data collected by the DBDSP show a dramatic increase in drilling activity, but no additional occurrences of pressurized brine within the monitoring area over the last 10 years. The DOE believes that these new data should be recognized and incorporated as appropriate into the CRA-2014.

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Kirchner, T.B. 2013. *Sensitivity of the CRA-2014 performance assessment releases to parameters*. ERMS 560043. Sandia National Laboratories, Carlsbad, NM.

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Popielak, R.S., Beauheim, R.L., Black, S.B., Coons, W.E., Ellingson, C.T., and R.L. Olsen. 1983. *Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP), Project Southeastern New Mexico.* TME-3153. Vols. 1 and 2. Westinghouse Electric Corporation, Carlsbad, NM.

Powers, D.W., Lambert, S.J., Shaffer, S-E., Hill, L.R., Weart, W.D. (eds.). 1978. *Geological Characterization Report Waste Isolation Pilot Plant (WIPP) Site. Southeastern New Mexico*. SAND78-1596, Volume II. Sandia National Laboratories, Albuquerque, NM.

Powers, D., J.M. Sigda and R.M. Holt. 1996. *Probability of intercepting a pressurized brine reservoir under the WIPP*. ERMS 523414. Sandia National Laboratories Albuquerque, NM.

Sandia. 1992. *Preliminary performance assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters*. SAND92-0700/3. Sandia National Laboratories, Albuquerque, NM.

Taylor, B.N. and C.E. Kuyatt. 1994. *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, NIST Technical Note 1297*. U.S. Department of Commerce, National Institutes of Standards and Technology, Gaithersburg, MD.*

The Earth Technologies Corporation. 1988. *Final Report for Time Domain Electromagnetic (TDEM) Surveys of the WIPP Site*. SAND87-7144. Sandia National Laboratories, Albuquerque, NM.

*Copyrighted reference not provided in Enclosure 2.

EPA Comment

1-23-8 Fluid Flow in Repository Operations and Experimental Areas. *There have been numerous refinements of conceptual and numerical models of repository fluid flow since the 1994-95 time frame as well as changes to the panel closure system that may also change repository fluid flow. Please provide updated technical justifications for the following parameter values adopted for the experimental and operations areas:*

1. *Setting the permeability of the operations and experimental rooms to a constant value of value 10^{-11} m^2 throughout the modeled period.*
2. *Setting the porosity of the operations and experimental rooms to a constant 18% throughout the modeled period.*
3. *Setting the porosity and permeability of the DRZ adjacent to the operations and experimental room to the same sampled value as the DRZ surrounding a waste panel throughout the modeled period.*

DOE Response

1. To remain consistent with previous, peer-reviewed conceptual models for the repository and for the Salado, performance assessment assigns constant porosity and permeability to the operations and experimental areas. Constant values for porosity and permeability in the experimental and operations areas are based on the concept that it is conservative in terms of releases if these areas have high permeability and low porosity. High permeability ensures that these regions do not impede brine and gas flow that might contribute to a borehole release and low porosity minimizes the storage capacity for gas in these regions, thus resulting in higher pressures in the waste-filled regions of the repository. The operational and experimental regions in the CRA-2014 PA are assigned a permeability of 10^{-11} m^2 and a porosity of 0.18 for the duration of the 10,000-year regulatory period, the same values established and used in the CCA, as well as the CRA-2004 and CRA-2009.

   Repository performance has been repeatedly shown to be insensitive to dynamic closure in the experimental and operations areas:

   1. During the development of the CCA, the DOE investigated whether it was important to include a dynamic model of creep closure in the experimental and operations areas. Calculations demonstrated that performance was quite insensitive to whether dynamic closure in these areas was included or not (Vaughn 1996).

   2. In response to a similar comment from the EPA (C-23-4), supplemental calculations to the CRA-2004 submittal demonstrated that the assignment of constant porosity and permeability in the experimental and operations areas remained a conservative assumption (Detwiler 2004).

   3. Following the CRA-2009 PABC, an impact assessment was undertaken to investigate the impact of additional mined volume in the WIPP experimental region on repository performance. An additional 60,335 m^3 were added to the CRA-2009 PABC BRAGFLO representation of the WIPP experimental region. It was found that increased volume in the experimental region had no impact on regulatory compliance curves obtained in the CRA-2009 PABC (Camphouse et al. 2011).

   4. The Salado flow analysis performed for the CRA-2014 PA compared results from the CRA-2009 PABC, the PCS-2012 PA, and Case CRA14-BL. In other words, it compared

Salado flow baseline results where the Option D PCS was implemented, results where the Option D PCS was replaced by the ROMPCS, and results where the ROMPCS was implemented with 60,335 m^3 of additional excavated volume added to the experimental region in BRAGFLO. Waste region pressure and brine saturation results for intrusion scenarios were found to be similar in all three cases (Camphouse 2013).

There have been no new conditions or changes that render the current representation inadequate or inconsistent with our current understanding of repository behavior. There is no reason at this time to modify the constant porosity and permeability values assigned to the operations and experimental areas.

2. The response to item 2 is contained in the response to item 1.

3. Parameter values for the DRZ adjacent to waste panels, and the operations and experimental regions, are defined for two time periods. The first time period corresponds to the time associated with waste emplacement in a fresh panel, and endures for 5 years prior to repository closing (-5 to 0 years). The second time period corresponds to the sealed repository time period from 0 to 10,000 years. At the start of the first time period (the instant the excavation is made), the DRZ is assumed to be fully brine-saturated and in hydrostatic equilibrium with the rest of the Salado Formation. For the second time period, the DRZ is assumed to be a well-developed region characterized by vertical fractures. Because of gas generation and the consequently increasing pressure in waste panels, the DRZ above and below repository waste regions is assumed not to heal. The effect of gas pressure is to reduce back stress applied by the waste. Moreover, pressure is gradually transmitted from the repository waste panels to the northern operations and experimental regions. As a result, the DRZ above and below the operations and experimental regions is also assumed not to heal. As increasing pressure is the driving mechanism inhibiting healing of the DRZ, and pressure increase is seen in repository waste regions as well as the northern operations and experimental areas, the porosity and permeability of the DRZ adjacent to the operations and experimental regions are set to the same sampled values as the DRZ surrounding waste panels. This implementation remains consistent with previous, peer-reviewed conceptual models for the repository and for the DRZ. There is no reason to modify these values at this time.

References:

Camphouse, R.C. 2013. *Analysis Package for Salado Flow Modeling Done in the 2014 Compliance Recertification Application Performance Assessment (CRA-2014 PA)*. ERMS 559980. Sandia National Laboratories, Carlsbad, NM.

Camphouse, R.C., D.C. Kicker, T.B. Kirchner, J.J. Long, and J.J. Pasch. 2011. *Impact Assessment of SDI Excavation on Long-Term WIPP Performance*. ERMS 555824. Sandia National Laboratories, Carlsbad, NM.

Camphouse, R.C., D.C. Kicker, T.B. Kirchner, J.J. Long, B. Malama, and T.R. Zeitler. 2012. *Summary Report and Run Control for the 2012 WIPP Panel Closure System Performance Assessment*. ERMS 558365. Sandia National Laboratories, Carlsbad, NM.

Camphouse, R.C., D.C. Kicker, S. Kim, T.B. Kirchner, J.J. Long, B. Malama, and T.R. Zeitler. 2013. *Summary Report for the 2014 WIPP Compliance Recertification Application Performance Assessment*. ERMS 560252. Sandia National Laboratories, Carlsbad, NM.

Detwiler, R.P. 2004. Partial Response to Environmental Protection Agency (EPA) May 20, 2004 Letter on CRA. ERMS 537372. Sandia National Laboratories, Carlsbad, NM.

Vaughn, P. 1996. *Phase I FEPS Composite FEP Records Screening Analysis*. ERMS 418211. Sandia National Laboratories, Carlsbad, NM.

EPA Comment

2-43-1 Changes in Passive Institutional Controls (PICs). *Recent Nuclear Energy Agency and International Atomic Energy Agency reports describe changes and developments in international approaches to PICs. These are referenced in INIS-US-13-WM-13145 which states "The DOE/CBFO WIPP PIC's program in place today meets the regulatory criteria, but complete feasibility of implementation is questionable, and may not be in conformance with the international guidance being developed." Please explain this feasibility concern. Please also provide the complete INIS-US-WM-13145 report (the Web link only provides an Abstract) and any other recent studies or reports that may impact PICs planning in the future.*

Reference:

INIS-US-13-WM-13145, "The Revised WIPP Passive International Controls Program – A Conceptual Plan – 13145, Dated 2013-07-01,
Web link: http://www.osti.gov/scitech/biblio/22225507

DOE Response

The reference INIS-US-13-WM-13145 is a Waste Management Symposia 2013 paper that outlines some preliminary thoughts on developing a revised WIPP PICs program. The paper is provided with this response and discusses the feasibility concerns in EPA comment 2-43-1.

DOE will discuss with EPA the current status of the development of international guidelines for PICs, which is outside of the context of the CRA-2014 completeness review.

EPA Comment
2-55-1 Incorrect Reference. *IGP-2014, Section IGP-2.1 makes reference to 194.55(b)(1), should this be 194.54(b)(1) "Existing boreholes…"?*

DOE Response

This is a typographical error in Appendix IGP-2014. The text will be corrected to read "Existing boreholes, as required by 40 CFR § 194.54(b)(1)…".

This typographical error has been added to Enclosure 4, *CRA-2014 Errata Tracking.*

EPA Comment

2-C-7 MgO Hydration Rate Data File. *Please provide a copy of the Microsoft Excel file "hydration kinetics Q & HY2 & HH djc 5-1-07.xls" used by Nowak and Clayton (2007) to calculate the MgO hydration rates.*

References:

Nowak, E.J. and D. Clayton. 2007. Analysis of MgO Hydration Laboratory Results and Calculation of Extent of Hydration and Resulting Water Uptake versus Time under Postulated WIPP Conditions. Sandia National Laboratories ERMS 546769.

DOE Response

The requested documentation is included in Enclosure 2.

EPA Comment

2-C-8 Iron and Lead Corrosion Rate Data. *Please provide spreadsheets containing the iron and lead corrosion data listed in Appendix A, Tables A-1 and A-2 from Roselle (2013).*

References:

Roselle, G.T. 2013. Determination of Corrosion Rates from Iron/Lead Corrosion Experiments to be Used for Gas Generation Calculations. Sandia National Laboratories ERMS 559077.

DOE Response

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Viewpoint

The coral reef crisis: The critical importance of <350 ppm CO_2

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ABSTRACT

Temperature-induced mass coral bleaching causing mortality on a wide geographic scale started when atmospheric CO_2 levels exceeded ~320 ppm. When CO_2 levels reached ~340 ppm, sporadic but highly destructive mass bleaching occurred in most reefs world-wide, often associated with El Niño events. Recovery was dependent on the vulnerability of individual reef areas and on the reef's previous history and resilience. At today's level of ~387 ppm, allowing a lag-time of 10 years for sea temperatures to respond, most reefs world-wide are committed to an irreversible decline. Mass bleaching will in future become annual, departing from the 4 to 7 years return-time of El Niño events. Bleaching will be exacerbated by the effects of degraded water-quality and increased severe weather events. In addition, the progressive onset of ocean acidification will cause reduction of coral growth and retardation of the growth of high magnesium calcite-secreting coralline algae. If CO_2 levels are allowed to reach 450 ppm (due to occur by 2030–2040 at the current rates), reefs will be in rapid and terminal decline world-wide from multiple synergies arising from mass bleaching, ocean acidification, and other environmental impacts. Damage to shallow reef communities will become extensive with consequent reduction of biodiversity followed by extinctions. Reefs will cease to be large-scale nursery grounds for fish and will cease to have most of their current value to humanity. There will be knock-on effects to ecosystems associated with reefs, and to other pelagic and benthic ecosystems. Should CO_2 levels reach 600 ppm reefs will be eroding geological structures with populations of surviving biota restricted to refuges. Domino effects will follow, affecting many other marine ecosystems. This is likely to have been the path of great mass extinctions of the past, adding to the case that anthropogenic CO_2 emissions could trigger the Earth's sixth mass extinction.

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1. Introduction

Temperature-related effects of global warming on coral reefs are highly visible, well-defined and extensively documented. Correlations between rising CO_2 levels, rising ocean temperature and the biological responses of reefs are therefore known in detail, providing a particularly well-grounded basis for future prediction. The more recently recognised effects of atmospheric CO_2 on ocean acidification will have even more profoundly detrimental long term effects on reefs but the full range of biological responses is, as yet, incompletely understood.

1.1. The importance of coral reefs

Although they make up only 0.2% in area of the marine environment, coral reefs are the most biodiverse ecosystems of the ocean, estimated to harbour around one third of all described marine species (Reaka-Kudla, 1997, 2001), most of which are found nowhere

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else. Their intricate three-dimensional landscapes promote elaborate adaptation, richly complex species interdependencies, and a fertile source of medically active compounds (Fenical, 2002; Bruckner, 2007). The extensive ramparts formed by reefs shield thousands of kilometres of coastline from wave erosion, protecting essential lagoon and mangrove habitat for vulnerable life stages of a wide range of commercial and non-commercial species (Johnson and Marshall, 2007).

More than 100 countries have coastlines with coral reefs (Moberg and Folke, 1999) and almost 500 million people (8% of the world's population) live within 100 km of a reef (Bryant et al., 1998). Consequently, tens of millions of people depend on reef ecosystems for protein and other services (Costanza et al., 1997). Resulting exploitation, combined with lack of regulation, has resulted in severe depletion of many reef resources and has caused widespread reef degradation particularly in highly populated regions (Pet-Soede et al., 1999). Despite these impacts, human dependence on reefs continues to increase. The values of goods and services provided by reefs have not been accurately determined, but estimates range from $172 billion to $375 billion per year (Moore and Best, 2001; Wilkinson, 2002; Fischlin et al., 2007; Martínez et al., 2007). This is probably underestimated given that many of the benefits of coral reefs pass through non-market economies (Donner and Potere, 2007) or involve intangible ecosystem services such as sand production and gas exchange.

Importantly, the consequences of coral reef destruction would not be limited to the loss of the value of these goods and services, for the demise of reefs would also mean the extinction of a large part of the Earth's total biodiversity – something never experienced before in human history.

1.2. Impacts of global warming

The fossil record of reefs provides an unparalleled window into the effects of climate change through geological time. In the broadest context, today's reef-forming corals have existed for 240 million years during which time they have been repeatedly decimated by climate changes from many different causes, most of which are linked to upheavals of the carbon cycle (Veron, 2008b). Although, on geological timescales reef ecosystems are clearly very persistent, the geological record offers crucial warnings that on human timescales reefs can indeed be lost, that a large proportion of coral and other calcifying species can go extinct and that once lost, reefs can take thousands to millions of years to re-establish. Perhaps most importantly, there is no evidence that reefs have ever experienced true parallels to today's anthropogenically-driven combination of stressors. At the rate at which these stressors are currently compounding we are going into uncharted waters (Veron, 2008a).

Already an estimated 19% of the world's coral reefs have been lost and a further 35% are seriously threatened (Wilkinson, 2008). As a result, one-third of all reef-building corals are considered to be at risk of extinction (Carpenter et al., 2008). To date, there have been a range of principal causes: predation by the coral-eating crown-of-thorns starfish, sedimentation from urban development and deforestation, over-fishing, destructive fishing practices, eutrophication from agriculture and sewage, pollution from herbicides and pesticides, diseases, and global warming. However, global warming has now overtaken all other impacts in importance because it is the cause of increasingly destructive and extremely widespread mass bleaching events (Hughes et al., 2003; Hoegh-Guldberg et al., 2007; Veron, 2008a).

The multiple nature of stressors on reefs associated with climate change is unprecedented in human history and studies of its synergisms are still in their infancy (for example, De'ath et al., 2009). It is however, virtually certain that the likely consequences of multiple impacts will be synergistic, and far more severe than indicated from studies of individual stressors.

2. Mass bleaching and mortality: the current crisis

Regionally significant mass bleaching of corals (bleaching of multiple species on an ecologically significant scale) was first observed in the late 1970s and was soon correlated with abnormally high sea temperatures, especially pulses naturally induced by El Niño events, which currently recur every 4–7 years (Glynn, 1984, 1990, 1991) superimposed on generally elevated sea temperatures due to global warming (Hoegh-Guldberg, 1999). Detailed surveys of mass bleaching were first conducted in 1979/1980 in the Caribbean and surrounding seas (Hughes, 1994) (notably in Jamaica and the Bahamas), the far eastern Pacific (Panama and the Galápagos Islands), in isolated instances in the Pacific (notably French Polynesia and Thailand) (Brown, 1997; Brown et al., 2000) and on the Great Barrier Reef (Berkelmans and Oliver, 1999; Berkelmans et al., 2004).

Although there are many other causes of more restricted bleaching in corals, the worldwide phenomenon colloquially known as 'mass bleaching' has been shown to require a combination of both sunlight and abnormally high water temperature (Hoegh-Guldberg, 1999). Small increases (1–2 °C) in sea temperature above the long-term summer maxima destabilises the relationship between host corals and their symbiotic dinoflagellate algae (zooxanthellae), on which they rely for energy and growth (Muscatine, 1973; Trench, 1979). In high light conditions, there is a breakdown of the photosymbiotic system which causes a toxic buildup of reactive oxygen derivatives and results in a loss of the brown algae from the tissues leaving them white or 'bleached'. If the effect is short-lived, corals may recover, otherwise they become prone to disease and death. This dependence on both light and temperature has been confirmed in corals kept in shaded aquaria (Jones et al., 1998 and many subsequent studies) as well as those growing naturally on reefs (Mumby et al., 2001).

Unlike most ecosystems where the effects of climate change are matters of future prediction, mass bleaching of corals has been studied for 30 years and is understood in considerable detail (Glynn, 1993; Buddemeier et al., 2004; van Oppen and Lough, 2008).

2.1. Carbon dioxide levels

When the mass bleaching of coral was first recorded (1978/79), the CO_2 level in the atmosphere was ~336 ppm (NOAA/ESRL, 2009). On the basis of an optimistic lag-time of 10 years,[2] this event may be considered the outcome of a CO_2 level of ~320 ppm. Since that time there have been seven major world-wide bleaching events. It was the 1982/83 mass bleaching that drew attention to the association between bleaching, CO_2 level, and ocean temperature (Glynn, 1984, 1990, 1991; Hoegh-Guldberg, 1999; Buddemeier et al., 2004). That summer, about two-thirds of all inshore reefs and about 14% of offshore reefs of the Great Barrier Reef had moderate to high levels of bleaching. CO_2 then was at a level of 340 ppm, with water temperatures reflecting a 10-year time-lagged response to <~326 ppm (NOAA/ESRL, 2009).

[2] Lag time is defined here as the time it takes for the temperature of the surface ocean and hence the atmosphere to equilibrate with any particular CO_2 level. It is generally estimated to be in the order of several decades. There can be no precise measurement of lag times when CO_2 levels are changing; however, it is at least a single decade, the time interval factored-in here. Note that if the lag time is assumed to be longer than 10 years, the equivalent forcing CO_2 level would be lower (i.e. worse). Deep ocean temperatures equilibrate with surface forcing over timescales approaching a millennium hence increasing the eventual surface temperature change for a given change in CO_2.

The 1997/1998 mass bleaching event killed approximately 16% of coral communities globally (Berkelmans and Oliver, 1999; Wilkinson, 2004). It was also the start of a decline from which there has been no significant long-term recovery. By then, the CO_2 level was ~365 ppm, with water temperatures reflecting a 10-year time-lagged response to a level of <350 ppm (NOAA/ESRL, 2009).

The 2002 mass bleaching event was particularly serious for Asia and the Great Barrier Reef (Berkelmans et al., 2004) and the 2005 event commenced a new phase of decline characterised by a diminishing habitat complexity in reefs of the Caribbean and a deterioration of species diversity (Alvarez-Filip et al., 2009).

It is now clear that the vulnerability of coral reefs to bleaching varies geographically (Cook et al., 1990; Jokiel and Coles, 1990; Aeby et al., 2003) according to resilience (Coles and Brown, 2003) (see below) which, in turn is dependent on the frequency and severity of bleaching (McClanahan et al., 2007; Sheppard et al., 2008), the thermal history of the location (Brown et al., 2000; Brown et al., 2002) and levels of other stressors, notably sedimentation, over-fishing and water quality (Hutchings et al., 2005; Johnson and Marshall, 2007). Significantly, although there are some taxonomic differences in susceptibility of both corals and algae to bleaching, it is virtually certain that all shallow-water zooxanthellate corals will ultimately succumb to bleaching if summer sea temperatures increase by 1–3 °C above their present long-term values, or if high sea temperature pulses become increasingly sustained.

2.1.1. The time-line

Apart from isolated occurrences of bleaching in severely stressed environments (for example, Yonge and Nicholls, 1931), there are no substantiated records of mass bleaching before the late 1970s. Further evidence that mass bleaching is a recent phenomenon is seen in long-lived corals, especially large colonies of *Porites* which can be over 600 years old and which have been dying en masse from bleaching since 1970.

Further back in time the potential existence of mass bleaching can only be inferred from possible temperature consequences of CO_2 highs. It is possible that clades of zooxanthellae not seen today may have occurred in past intervals of high temperature, the most recent being the temperature peaks of the Pliocene (5–2.6 million years ago), especially if temperature increase occurred sufficiently slowly for evolutionary adaptation to occur. Since the Pliocene peaks, global temperatures, though variable, have been only marginally higher than at present (Haywood and Williams, 2005) and there is no evidence that rates of global temperature increase relevant to the thermal thresholds of corals were anywhere near as rapid as they are today (Robinson et al., 2008). There is thus no reason to believe that mass bleaching would have been a major stress on reefs at any time since the temperature peaks of the Pliocene.

In contrast, the future path of mass bleaching events is only too clear. Rising sea surface temperatures will lead to increased severity of El Niño-associated thermal anomalies and consequently mass bleaching (Sheppard, 2003; Hoegh-Guldberg et al., 2007; Veron, 2008a; Baker et al., 2008). Current models predict an increase in the amplitude of the El Niño Southern Oscillation with no change in frequency (Guilyardi, 2006). However, incidence of mass bleaching is now likely to de-couple from El Niño cycles in many parts of the world as indicated by the observation that damaging temperatures are already starting to occur during non-El Niño years. This will put affected reefs at increasing annual risk, greatly shortening event return times and decreasing resilience (Sheppard, 2003).

Some reefs, notably those of the southern Red Sea (which has naturally high temperature) and parts of the 'Coral Triangle' (Roberts et al., 2002; Hoegh-Guldberg et al., 2009; Veron et al., 2009) (which has natural refugia) are likely to be relatively less vulnerable to mass bleaching as are other locations which could benefit from temporary changes in water circulation. Nevertheless, such effects can only offer a short-term reprieve: at the current rate of increase in global CO_2 emissions (now exceeding 3% per year) a level of 450 ppm, which far exceeds the most optimistic outlook for the viability of almost all reefs, will be reached in the 2030s (Meehl et al., 2007; Raupach et al., 2007). The result will be widespread destruction of coral communities, with a few persisting in shaded, turbid waters or at depth (generally below 20 m in clear water). The major issue here is that reef-building corals will become rare members of tropical reef assemblages, threatening the ecological services provided by coral reefs to tens of thousands of other dependent species as well as coastal human societies.

In the very long term (centuries to millennia) mass bleaching alone is unlikely to cause widespread extinctions of corals because the complexities of reef topographies provide refuges from which re-seeding could occur. Such refuges, however, may not provide protection for other taxa restricted to shallow-water reef habitats and will not provide protection for corals from ocean acidification which looms as an even more serious threat.

3. Ocean acidification

Prior to the industrial revolution, absorption and release of CO_2 by the oceans was in approximate equilibrium (Watson and Orr, 2003). Since then, atmospheric CO_2 has risen from ~280 ppm to today's level of ~387 ppm (NOAA/ESRL, 2009) and is estimated to be increasing at a rate at least 100 times faster than has occurred naturally for at least the past 650,000 years (Siegenthaler et al., 2005). About half of all CO_2 from anthropogenic sources still remains in the atmosphere (Houghton, 2007). A further 20% has been taken up by terrestrial life and the remaining 30% has been taken up by the oceans, a process that has now used up about one-third of the storage capacity of the ocean surface (Sabine et al., 2004). This uptake by the oceans is causing acidification of surface waters because dissolved CO_2 forms carbonic acid which alters the ratio of the pH-maintaining carbonate/bicarbonate buffers which in turn decreases pH (Feely et al., 2004; Raven et al., 2005). These changes are now clearly observable in cold high latitude oceans where CO_2 is relatively soluble (Mayewski et al., 2009). On current trajectories of atmospheric CO_2 levels, the acidification process, already underway in high latitudes, will severely impact the tropics by 2030–2050 at which time all reefs of the world will be under increasing acidification stress (Cao et al., 2007; Meehl et al., 2007).

Although correlations between CO_2 levels, depth changes in ocean chemistry and geographic patterns of acidification that result are imperfectly known, the process itself is not in doubt (Buddemeier et al., 2004; Orr et al., 2005). Historically, studies of carbonate compensation depths have been based on calcite, the dominant form of calcium carbonate, but coral skeletons are made of aragonite, which is more soluble.

3.1. Aragonite saturation

Shallow tropical seawater is supersaturated with respect to aragonite ($\Omega_{aragonite} > 4$), but saturation levels have fallen significantly over the past century (from 4.6 to 4.0) and will continue to fall as atmospheric CO_2 rises (Kleypas and Langdon, 2006). Although field confirmation is in its early stages there is growing evidence of sub-lethal changes on tropical reefs that are consistent with predicted responses to acidification (see below). It is therefore probable that most sub-tropical reefs are already in sub-optimal condition, although more research is needed to verify this. When atmospheric CO_2 reaches 560 ppm, most ocean surface waters will be adversely undersaturated with respect to aragonite and the pH will have reduced by about 0.24 units – from almost 8.2 today to just over 7.9.

At this point (sometime in the third quarter of this century at current rates of increase) only a few parts of the Pacific will have levels of aragonite saturation adequate for coral growth (Guinotte et al., 2003) and all will be stressed by climate-related synergies (see below). If CO_2 levels are allowed to reach 800 ppm, the pH decrease will be 0.4 units (Riebesell et al., 2000; Orr et al., 2005) and total dissolved carbonate ion concentration will have decreased by at least 60%. At this point it is almost certain that all reefs of the world will be in erosional states (Veron, 2008a; Hoegh-Guldberg et al., 2009). Impacts will be further exacerbated in coastal areas from atmospheric pollutants forming nitric and sulphuric acids (Doney et al., 2007).

The levels of CO_2 and pH predicted around the end of this century may not have occurred since the Middle Eocene (Caldeira and Wickett, 2003). However, the all-important rate of change we are currently experiencing may have no precedent over any time scale (for example, Zachos et al., 2008).

3.2. Impacts on reef biota

Although much is known about the chemistry of ocean acidification described above, its biological effects are likely to be complex (Kleypas et al., 2006). The vulnerability of different taxa to acidification depends on the form of carbonate that they secrete. Coralline algae, which are essential for cementing coral rubble into solid reef and which form a critical habitat for the early life history stages of many organisms including corals, secrete high magnesium calcite and are therefore particularly vulnerable to acidification (Kuffner et al., 2007; Jokiel et al., 2008). Coral skeletons are formed of aragonite and most molluscs have shells of calcite.

There is a roughly direct relationship between aragonite saturation and the capacity of corals to calcify when temperatures are near optimum levels (Langdon et al., 2000; Barker and Elderfield, 2002; Feely et al., 2004). This can be studied experimentally (Langdon, 2002) although most effects on reefs will be ecological responses to decreased growth rates and skeletal strength. A decrease in coral growth rate of 14% since 1990 (and unprecedented in the 400 year record examined) has already been observed on corals of the Great Barrier Reef, as a possible response to acidification in combination with elevated temperature stress (Cooper et al., 2008; De'ath et al., 2009). Comparable observations have been made in Thailand (Tanzil et al., 2009) and the Caribbean (Bak et al., 2009).

When CO_2 levels reach approximately 450 ppm, calcification of coralline algae will probably be completely inhibited (Kleypas and Langdon, 2006; Anthony et al., 2008) while calcification of reef-building corals will be reduced by up to 50% (Guinotte et al., 2003; Silvermann et al., 2009) even without consideration of further harmful synergies. Branching corals, especially shallow-water *Acropora* which are primary habitat builders, will become brittle and more easily damaged leading to extensive habitat deterioration. Overall reef building processes will be severely diminished or will cease altogether (Gattuso et al., 1998, 1999; Kleypas et al., 1999; Langdon and Atkinson, 2005) because as much as 90% of carbonates involved in reef building are removed by erosion, even under ideal building conditions. Average decreases in calcification of more than about 10–20% are expected to put most if not all coral reefs into a net negative carbonate budget where reef structures and frameworks are no longer maintained (Hoegh-Guldberg et al., 2007). At 800 ppm, all calcification including that of calcite-secreting molluscs, will cease or be greatly reduced.

Changes in ocean acidification are also likely to have impacts on a range of biological processes in addition to calcification, including impacts on photosynthesis, oxygen exchange and reproduction (see below). Understanding of these changes and their consequences is in its infancy, but most research indicates that relatively subtle changes in dissolved carbon dioxide and pH can potentially have large-scale impacts (Raven et al., 2005).

4. Critical issues

Three issues of particular importance to the future of coral reefs are highlighted in this article: (1) the role of multiple stressors and synergies, (2) the nature of resilience and (3) the importance of domino effects.

4.1. Multiple stressors

Reef deterioration may occur as a direct response to an individual stressor such as mass bleaching, but it more commonly occurs in response to combinations of different stressors acting simultaneously and often synergistically (Sheppard, 2006; Baker et al., 2008). Rising sea-levels, increasing numbers of high intensity storms, deterioration in water quality and various biotic influences are the principal stressors that will exacerbate the effects of mass bleaching and ocean acidification. It has been shown, for example, that corals bleach at lower temperatures in acidified water (Anthony et al., 2008). Although studies of these complex interactions are at a very early stage it is clear that they substantially hasten the deterioration of reefs.

4.1.1. Sea-level changes

The greatest sea-level changes that have taken place in geological time have been due to slow changes (over millions of years) in the shape of ocean basins, not to the much more rapid (millennia-long) changes of ice volume that have caused the sea-level variations of the Pleistocene. However, in both cases, coral communities have successfully re-located, something which they are clearly able to do (even accommodating an abrupt rise of 36 mm/yr at the termination of the last glaciation (Blanchon et al., 2009). Anticipated rates of sea-level change this century ($\geqslant$10 mm/yr) (Hansen, 2004; Church and White, 2006; Richardson et al., 2009) are greater than normal rates of reef growth ($\sim$6 mm/yr) (Vecsei, 2004; Montaggioni, 2005). As the rate of sea-level change increases it will likely have a material impact in synergy with other stressors, especially ocean acidification and high-impact weather events, driving shallow reef communities towards an erosional state. This effect of sea-level rise is not likely to be significant for reefs until mid-century but will be preceded by deterioration of living conditions on human-occupied atolls.

4.1.2. Storm impacts

Predicted increases in the frequency and severity of high-energy storms partly due to increases in ocean surface temperature (Emanuel, 2005; Webster et al., 2005) may already be affecting reefs in some geographic regions including the Great Barrier Reef (Nott and Hayne, 2001). The damage from such storms will be exacerbated by weakening of the reef structure resulting from increasing acidification. Increases in rainfall from changed weather events can also be damaging to reefs as demonstrated by very destructive rainfall on the Great Barrier Reef in 2009 (Great Barrier Reef Marine Park Authority, in press). In some geographic regions, changes in the seasonal pattern of rainfall poses a risk to annual reproductive cycles of corals as surface-born coral larvae are intolerant of low salinity.

4.1.3. Fisheries impacts

Over-fishing affects almost all reefs to varying degrees, while destructive fishing, notably blast fishing, is more geographically confined, but its effects can be intense. The close connection between healthy fish communities and wider reef health has long

been known (Hughes, 1994; Roberts, 1995), although more recent studies have greatly enhanced our understanding of this relationship. The removal of top predators, especially sharks, reduces overall species diversity and alters the trophic structure, leading to loss of biomass and the demise of other critical trophic groups including many larger herbivores (Friedlander and DeMartini, 2002; Dulvy et al., 2004; Knowlton and Jackson, 2008). This, and the widespread direct removal of herbivorous fish, allows macro-algae to overgrow corals and to prevent resettlement of new corals in damaged reefs (Aronson and Precht, 2006; Hughes et al., 2007). Destructive fishing destroys the very structure of the reef as well as living communities and often leaves loose rubble which can take many years to recover (Burke et al., 2002; Fox et al., 2005). Overall, where fishing impacts can be minimised, the diverse and productive ecosystems which result appear to be more resilient and recover more rapidly from bleaching or other perturbations (Hughes et al., 2007).

4.1.4. Water quality

Coral reefs and coral communities are highly sensitive to water quality, largely a matter of sediment loads (which affects light penetration), nutrients and environmental contaminants. Terrestrial runoff from urban development, agriculture and deforestation are the principal causes of diminished water quality (Fabricius, 2005). Runoff impacts have become such a worldwide phenomenon, that only reefs well removed from highly populated land masses have escaped degradation of some sort. This is now the subject of considerable research and mitigation expenditure on the Great Barrier Reef (Furnas, 2003; Hutchings et al., 2005) as it offers one of the few management options that will enhance reef resilience prior to critical threshold levels being reached due to climate change.

4.1.5. Biotic responses

Widespread observations have been made of the impacts of pathogen and parasite outbreaks on keystone marine species in coral reef environments causing coral diseases, but also impacting echinoderms, turtles and seagrasses (Harvell et al., 2004; Ward and Lafferty, 2004). Predator outbreaks such as the crown of thorns starfish, also have significant impacts on many reefs. There is evidence that many of these impacts are increasing in frequency and expanding their geographic scope. Such impacts may be symptoms of a wider malaise, with increasing prevalence linked to the poor health of the patient/host as a result of other human impacts. Importantly there is also growing evidence of synergies between these impacts and other stressors, particularly with coral bleaching (Miller et al., 2006; Bruno et al., 2007; Harvell et al., 2007).

It is also important to consider the biotic response to existing mass bleaching and coral mortality. Even where corals recover from mass bleaching there is likely to be reduction in growth and fecundity. Coral communities destroyed by bleaching can be quickly reduced to beds of debris which have little of the biodiversity of healthy reefs. These can recover if the frequency of bleaching events and resilience allow, but will go into a state of ecological collapse if conditions for recovery are inadequate. When this happens, the substrate may become covered with blue–green cyanobacterial slime (Veron, 2008a), a covering which appears to be ecologically stable. In such cases, only some macro-algae, notably *Halimeda*, can form any sort of three-dimensional re-growth supporting only a tiny fraction of the former reef diversity.

4.2. Resilience

Resilience – the capacity of a reef to recover from major disturbance – is primarily determined by the frequency, intensity and nature of stressors, the extent and nature of the damage, and the 'health' of the reef and its environment.

Since their first occurrences in the late 1970s, most mass bleaching events in the Indo-Pacific have been linked to El Niño cycles which occur at intervals of 4–7 years. The intensity of events has varied, but at these frequencies most reefs have made at least partial recovery (Bruno and Selig, 2007; Wakeford et al., 2008). In future, mass bleaching events will become more frequent as they de-couple from El Niño cycles, and more severe as ocean temperatures rise. They are currently on track to become annual events, with lethal temperature thresholds being reached most summers (Veron, 2008a). As the frequency and intensity of bleaching events rise, the extent and number of reefs involved will also rise, involving ever-increasing numbers of species over increasing depth-ranges. As this damage becomes more extensive, the capacity of corals to regrow from fragments or from immigration of larvae will inevitably decline.

A degraded environment, whether natural or human-induced, has a strong influence on reef resilience. Thus, over-fishing and water quality degradation (through increased sedimentation and nutrient pollution, as commonly occurs throughout the Caribbean, south-east Asia and the Indian Ocean perimeter) reduce the resilience of reefs to bleaching (Wilkinson, 2008). These chronically stressed reefs are now at high risk of reverting to semi-permanent algal or cyanobacterial communities (Veron, 2008a). In contrast, reefs remote from additional human stresses can make rapid recoveries (Aronson and Precht, 2006; Grimsditch and Salm, 2006; Hughes et al., 2007), returning to their former diversity in as little as a decade.

There is substantial geographic variation in temperature thresholds for bleaching. During the time of early mass bleaching events, the occurrence of unbleached corals in areas of naturally high temperatures (notably the southern Red Sea and Persian/Arabian Gulf) suggested a substantial degree of natural tolerance. However, most of these areas have more recently been damaged to some extent (Wilkinson, 2008). In short, the temperature at which bleaching occurs varies geographically, but the incidence of bleaching is almost universal.

Genetic diversity among corals and zooxanthellae can potentially enable adaptation, and thereby enhance resilience. Where there has been sufficient time and suitable conditions, many reefs that have been impacted by bleaching have recovered or are in the process of recovery (Sheppard et al., 2002; Sheppard and Obura, 2005; Grimsditch and Salm, 2006; Lasagna et al., 2008). This can involve an increase in the temperature tolerance of individual colonies by a shift to relatively heat-tolerant clades of zooxanthellae in surviving colonies (Brown et al., 2002; Thornhill et al., 2006; Maynard et al., 2008). Such modification of symbioses is important (Baker, 2001; Obura, 2009), but it is very unlikely to offer any long-term solution to mass bleaching because of a mismatch in time scales. The time scale of current impacts is in years to decades whereas that of evolutionary adaptation for highly dispersed long-lived animals like corals is in millennia at least. It is important to note that these changes also necessarily involve a narrowing of the genetic diversity within a population and hence a likely reduction in resilience to other stress factors.

4.3. Domino effects

Coral reefs occupy a truly unique position on Earth, for they are geological structures made by combinations of living organisms that have evolved the capacity to harness the abundant resources of air, seawater and sunlight. Reefs grow on solid substrates, but only at the interface of sea and atmosphere and only where light and temperature permit. To do this, reef-building organisms have evolved complex ecologies with tight interdependencies between

key species, all dominated by many types of symbiotic relationships between plants and animals.

Reefs are particularly vulnerable to environmental changes, especially disruptions to the pathways of the carbon cycle on which they are totally dependent. Unlike any other major ecosystem, such disruptions can be of both marine and terrestrial origin. It is therefore hardly surprising that reefs have been especially impacted by all the great mass extinction events of the past (Sepkoski, 1995; Stanley, 2001).

The outlook for reefs in the face of today's rapid global warming is exceptionally serious. The mounting evidence warning of the imminent demise of reefs is perhaps the strongest signal yet that the planet is on the brink of an environmentally-led mass extinction, for this appears to have been what happened in the remote past (Veron, 2008b). Whether or not this is so, reefs are likely to be the first major planetary-scale ecosystem to collapse in the face of climate changes now in progress (Sheppard et al., 2009). This raises the question: will this collapse be restricted to reefs or does it have wider implications? It is already clear that, although mass bleaching is a reef phenomenon, the effects of ocean acidification (Mcleod et al., 2008; UNESCO, 2009) will directly impact all carbonate-dependent taxa: not only corals, but calcareous algae, most molluscs, many crustaceans, echinoderms and planktonic taxa, and other groups that rely on carbonates for skeletal growth (Pörtner et al., 2004; Guinotte and Fabry, 2008). This includes fish (Munday et al., 2008) which are particularly vulnerable during early stages in their life-cycle (Kikkawa et al., 2004; Ishimatsu et al., 2004) and also the pelagic ecosystem of the Southern Ocean (Moy et al., 2009) which is dependent on krill. Research on these issues is still in its infancy, but the enormity of the threat is nevertheless real.

As far as the immediate future is concerned, the failure of reefs will have knock-on effects to other reef-associated ecosystems (Fabry et al., 2008). These impacts have been reviewed for the Great Barrier Reef (Pandolfi et al., 2003; Fabricius et al., 2007; Johnson and Marshall, 2007; Lough, 2007) and associated island biota (Turner and Batianoff, 2007), seagrass beds (Waycott et al., 2007; Björk et al., 2008), mangroves (Mcleod and Salm, 2006), marine reptiles (Hamann et al., 2007), marine mammals (Lawler et al., 2007), seabirds (Congdon et al., 2007), pelagic ecosystems (Kingsford and Welch, 2007) and estuarine habitats (Sheaves et al., 2007).

5. Remedial options

The speed at which climate change is impacting reef ecosystems leaves little opportunity for evolutionary processes to come to the aid of corals and other reef inhabitants as they would have done over geological intervals of time. Survival will be highly dependent upon any natural resistance already existing in the gene pools today. Some management interventions will, for a time, increase reef resilience, the most important of which are (a) reducing the harvest of herbivorous fish to sustainable levels (Hughes et al., 2007), (b) maintaining an effective trophic pyramid by protecting sharks and other top predators, (c) managing all aspects of water quality and (d) minimising any other direct anthropogenic impacts and stressors. Such actions can be supported through the use of large networks of marine protected areas and other direct management interventions such as improved control of watershed-based activities whose effects on water quality are often severe. Most of these management activities are already in place for the Great Barrier Reef Marine Park (Great Barrier Reef Marine Park Authority, 2009) and must be a priority for all reef regions. A wider array of other actions have also been recommended (Mcleod et al., 2008). Nevertheless, these actions cannot offer long-term protection from the consequences of increasing atmospheric CO_2 levels as they pass critical thresholds.

Efforts at emissions reductions have thus far been limited in magnitude and weak in implementation, and it is critical that this situation is reversed to enable rapid and dramatic cuts (Vaughan et al., 2009; Royal Society, 2009). However, cumulative carbon emissions to date have already committed atmospheric CO_2 to remaining above 330 ppm for at least the next millennium[3] (Lenton, 2006). Thus, to return to a safe level for corals will demand maintaining, enhancing and probably creating carbon dioxide sinks in addition to strong cuts to CO_2 emissions (Lenton and Vaughan, 2009). If such a strategy is pursued, it will be critical to consider all possible benefits and limitations and employ great caution, before allowing planetary scale carbon dioxide removal schemes to proceed (Royal Society, 2009). Some large scale carbon dioxide removal options such as ocean fertilization still require proof of their effectiveness and may risk serious side effects (Harvey, 2008; Lenton and Vaughan, 2009; Royal Society, 2009). Alternative climate geoengineering options, which involve a reduction in the amount of solar radiation absorbed by the Earth, will have no effect on ocean acidification (Blackstock et al., 2009).

As custodians of geological history, reefs offer both immense geological evidence and stark recent testimony to the potentially catastrophic effects of destabilising global climate. Although, being carbonate platforms, they are particularly sensitive to disruptions of the carbon cycle, their demise is symptomatic of damage to the entire biosphere as this cycle plays a dominant part in all ecosystems. When taken together, the abruptly accelerating deterioration of terrestrial and marine ecosystems and the increasingly disturbing global extinction rates may eventually become indistinguishable from the records of mass extinctions captured in the remains of long-fossilised coral reefs. The difference is that this time humanity will have been the cause and also one of the species to suffer.

The extreme gravity of the current predicament is now widely acknowledged by reef and climate scientists. It is also acknowledged that only drastic action starting now will prevent wholesale destruction of reefs and other similarly affected ecosystems. Should humanity not be successful in preventing these threats from becoming reality (Rojelj et al., 2009), no amount of management or expenditure will save future generations from the consequences of our failed guardianship.

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[3] Over 350 PgC have been emitted from fossil fuel burning and 165 PgC from land use change to date, equivalent to nearly 250 ppm. The airborne fraction of added CO_2 remains around 20% on the millennial timescale, i.e. 50 ppm of the already added CO_2 will be with us for over a 1000 years. Adding this to the preindustrial level of 280 ppm gives 330 ppm.

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No. 18232

MULTILATERAL

Vienna Convention on the law of treaties (with annex). Concluded at Vienna on 23 May 1969

Authentic texts: English, French, Chinese, Russian and Spanish.
Registered ex officio *on 27 January 1980.*

MULTILATÉRAL

Convention de Vienne sur le droit des traités (avec annexe). Conclue à Vienne le 23 mai 1969

Textes authentiques : anglais, français, chinois, russe et espagnol.
Enregistrée d'office le 27 janvier 1980.

VIENNA CONVENTION[1] ON THE LAW OF TREATIES

The States Parties to the present Convention,

Considering the fundamental role of treaties in the history of international relations,

Recognizing the ever-increasing importance of treaties as a source of international law and as a means of developing peaceful co-operation among nations, whatever their constitutional and social systems,

Noting that the principles of free consent and of good faith and the *pacta sunt servanda* rule are universally recognized,

Affirming that disputes concerning treaties, like other international disputes, should be settled by peaceful means and in conformity with the principles of justice and international law,

Recalling the determination of the peoples of the United Nations to establish conditions under which justice and respect for the obligations arising from treaties can be maintained,

Having in mind the principles of international law embodied in the Charter of the United Nations, such as the principles of the equal rights and self-determination of peoples, of the sovereign equality and independence of all States, of non-interference in the domestic affairs of States, of the prohibition of the threat or use of force and of universal respect for, and observance of, human rights and fundamental freedoms for all,

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[1] Came into force on 27 January 1980, i.e., on the thirtieth day following the date of deposit of the thirty-fifth instrument of ratification or accession with the Secretary-General of the United Nations, in accordance with article 84 (1):

State	Date of deposit of the instrument of ratification or accession (a)		State	Date of deposit of the instrument of ratification or accession (a)	
Argentina*	5 December	1972	Morocco*	26 September	1972
Australia	13 June	1974 *a*	Nauru	5 May	1978 *a*
Austria	30 April	1979 *a*	New Zealand	4 August	1971
Barbados	24 June	1971	Niger	27 October	1971 *a*
Canada*	14 October	1970 *a*	Nigeria	31 July	1969
Central African Republic	10 December	1971 *a*	Paraguay	3 February	1972 *a*
Cyprus	28 December	1976 *a*	Philippines	15 November	1972
Denmark*	1 June	1976	Republic of Korea	27 April	1977
Finland*	19 August	1977	Spain	16 May	1972 *a*
Greece	30 October	1974 *a*	Sweden	4 February	1975
Holy See	25 February	1977	Syrian Arab Republic*	2 October	1970 *a*
Honduras	20 September	1979	Togo	28 December	1979 *a*
Italy	25 July	1974	Tunisia*	23 June	1971 *a*
Jamaica	28 July	1970	United Kingdom of Great Britain and Northern Ireland*	25 June	1971
Kuwait*	11 November	1975 *a*	United Republic of Tanzania*	12 April	1976 *a*
Lesotho	3 March	1972 *a*	Yugoslavia	27 August	1970
Mauritius	18 January	1973 *a*	Zaire	25 July	1977 *a*
Mexico	25 September	1974			

Subsequently, the Convention came into force for the following State on the thirtieth day following the date of deposit of its instrument of ratification or accession with the Secretary-General of the United Nations, in accordance with article 84 (2):

State	Date of deposit of the instrument of accession (a)
Rwanda	3 January 1980 *a*

(With effect from 2 February 1980.)

* For the texts of the reservations and declarations made upon ratification or accession, see p. 501 of this volume.

Believing that the codification and progressive development of the law of treaties achieved in the present Convention will promote the purposes of the United Nations set forth in the Charter, namely, the maintenance of international peace and security, the development of friendly relations and the achievement of co-operation among nations,

Affirming that the rules of customary international law will continue to govern questions not regulated by the provisions of the present Convention,

Have agreed as follows:

PART I. INTRODUCTION

Article 1. SCOPE OF THE PRESENT CONVENTION

The present Convention applies to treaties between States.

Article 2. USE OF TERMS

1. For the purposes of the present Convention:

(*a*) "Treaty" means an international agreement concluded between States in written form and governed by international law, whether embodied in a single instrument or in two or more related instruments and whatever its particular designation;

(*b*) "Ratification", "acceptance", "approval" and "accession" mean in each case the international act so named whereby a State establishes on the international plane its consent to be bound by a treaty;

(*c*) "Full powers" means a document emanating from the competent authority of a State designating a person or persons to represent the State for negotiating, adopting or authenticating the text of a treaty, for expressing the consent of the State to be bound by a treaty, or for accomplishing any other act with respect to a treaty;

(*d*) "Reservation" means a unilateral statement, however phrased or named, made by a State, when signing, ratifying, accepting, approving or acceding to a treaty, whereby it purports to exclude or to modify the legal effect of certain provisions of the treaty in their application to that State;

(*e*) "Negotiating State" means a State which took part in the drawing up and adoption of the text of the treaty;

(*f*) "Contracting State" means a State which has consented to be bound by the treaty, whether or not the treaty has entered into force;

(*g*) "Party" means a State which has consented to be bound by the treaty and for which the treaty is in force;

(*h*) "Third State" means a State not a party to the treaty;

(*i*) "International organization" means an intergovernmental organization.

2. The provisions of paragraph 1 regarding the use of terms in the present Convention are without prejudice to the use of those terms or to the meanings which may be given to them in the internal law of any State.

Article 3. INTERNATIONAL AGREEMENTS NOT WITHIN THE SCOPE OF THE PRESENT CONVENTION

The fact that the present Convention does not apply to international agreements concluded between States and other subjects of international law or between such other subjects of international law, or to international agreements not in written form, shall not affect:

(*a*) The legal force of such agreements;

(*b*) The application to them of any of the rules set forth in the present Convention to which they would be subject under international law independently of the Convention;

(*c*) The application of the Convention to the relations of States as between themselves under international agreements to which other subjects of international law are also parties.

Article 4. NON-RETROACTIVITY OF THE PRESENT CONVENTION

Without prejudice to the application of any rules set forth in the present Convention to which treaties would be subject under international law independently of the Convention, the Convention applies only to treaties which are concluded by States after the entry into force of the present Convention with regard to such States.

Article 5. TREATIES CONSTITUTING INTERNATIONAL ORGANIZATIONS AND TREATIES ADOPTED WITHIN AN INTERNATIONAL ORGANIZATION

The present Convention applies to any treaty which is the constituent instrument of an international organization and to any treaty adopted within an international organization without prejudice to any relevant rules of the organization.

PART II. CONCLUSION AND ENTRY INTO FORCE OF TREATIES

SECTION 1. CONCLUSION OF TREATIES

Article 6. CAPACITY OF STATES TO CONCLUDE TREATIES

Every State possesses capacity to conclude treaties.

Article 7. FULL POWERS

1. A person is considered as representing a State for the purpose of adopting or authenticating the text of a treaty or for the purpose of expressing the consent of the State to be bound by a treaty if:

(*a*) He produces appropriate full powers; or

(*b*) It appears from the practice of the States concerned or from other circumstances that their intention was to consider that person as representing the State for such purposes and to dispense with full powers.

2. In virtue of their functions and without having to produce full powers, the following are considered as representing their State:

(*a*) Heads of State, Heads of Government and Ministers for Foreign Affairs, for the purpose of performing all acts relating to the conclusion of a treaty;

(*b*) Heads of diplomatic missions, for the purpose of adopting the text of a treaty between the accrediting State and the State to which they are accredited;

(*c*) Representatives accredited by States to an international conference or to an international organization or one of its organs, for the purpose of adopting the text of a treaty in that conference, organization or organ.

Article 8. SUBSEQUENT CONFIRMATION OF AN ACT PERFORMED WITHOUT AUTHORIZATION

An act relating to the conclusion of a treaty performed by a person who cannot be considered under article 7 as authorized to represent a State for that purpose is without legal effect unless afterwards confirmed by that State.

Article 9. ADOPTION OF THE TEXT

1. The adoption of the text of a treaty takes place by the consent of all the States participating in its drawing up except as provided in paragraph 2.

2. The adoption of the text of a treaty at an international conference takes place by the vote of two thirds of the States present and voting, unless by the same majority they shall decide to apply a different rule.

Article 10. AUTHENTICATION OF THE TEXT

The text of a treaty is established as authentic and definitive:

(*a*) By such procedure as may be provided for in the text or agreed upon by the States participating in its drawing up; or

(*b*) Failing such procedure, by the signature, signature *ad referendum* or initialling by the representatives of those States of the text of the treaty or of the Final Act of a conference incorporating the text.

Article 11. MEANS OF EXPRESSING CONSENT TO BE BOUND BY A TREATY

The consent of a State to be bound by a treaty may be expressed by signature, exchange of instruments constituting a treaty, ratification, acceptance, approval or accession, or by any other means if so agreed.

Article 12. CONSENT TO BE BOUND BY A TREATY EXPRESSED BY SIGNATURE

1. The consent of a State to be bound by a treaty is expressed by the signature of its representative when:

(*a*) The treaty provides that signature shall have that effect;

(*b*) It is otherwise established that the negotiating States were agreed that signature should have that effect; or

(*c*) The intention of the State to give that effect to the signature appears from the full powers of its representative or was expressed during the negotiation.

2. For the purposes of paragraph 1:

(*a*) The initialling of a text constitutes a signature of the treaty when it is established that the negotiating States so agreed;

(*b*) The signature *ad referendum* of a treaty by a representative, if confirmed by his State, constitutes a full signature of the treaty.

Article 13. CONSENT TO BE BOUND BY A TREATY EXPRESSED BY AN EXCHANGE OF INSTRUMENTS CONSTITUTING A TREATY

The consent of States to be bound by a treaty constituted by instruments exchanged between them is expressed by that exchange when:

(*a*) The instruments provide that their exchange shall have that effect; or

(*b*) It is otherwise established that those States were agreed that the exchange of instruments shall have that effect.

Article 14. CONSENT TO BE BOUND BY A TREATY EXPRESSED BY RATIFICATION, ACCEPTANCE OR APPROVAL

1. The consent of a State to be bound by a treaty is expressed by ratification when:

(*a*) The treaty provides for such consent to be expressed by means of ratification;

(*b*) It is otherwise established that the negotiating States were agreed that ratification should be required;

(*c*) The representative of the State has signed the treaty subject to ratification; or

(*d*) The intention of the State to sign the treaty subject to ratification appears from the full powers of its representative or was expressed during the negotiation.

2. The consent of a State to be bound by a treaty is expressed by acceptance or approval under conditions similar to those which apply to ratification.

Article 15. CONSENT TO BE BOUND BY A TREATY EXPRESSED BY ACCESSION

The consent of a State to be bound by a treaty is expressed by accession when:

(*a*) The treaty provides that such consent may be expressed by that State by means of accession;

(*b*) It is otherwise established that the negotiating States were agreed that such consent may be expressed by that State by means of accession; or

(*c*) All the parties have subsequently agreed that such consent may be expressed by that State by means of accession.

Article 16. EXCHANGE OR DEPOSIT OF INSTRUMENTS OF RATIFICATION, ACCEPTANCE, APPROVAL OR ACCESSION

Unless the treaty otherwise provides, instruments of ratification, acceptance, approval or accession establish the consent of a State to be bound by a treaty upon:

(*a*) Their exchange between the contracting States;

(*b*) Their deposit with the depositary; or

(*c*) Their notification to the contracting States or to the depositary, if so agreed.

Article 17. CONSENT TO BE BOUND BY PART OF A TREATY AND CHOICE OF DIFFERING PROVISIONS

1. Without prejudice to articles 19 to 23, the consent of a State to be bound by part of a treaty is effective only if the treaty so permits or the other contracting States so agree.

2. The consent of a State to be bound by a treaty which permits a choice between differing provisions is effective only if it is made clear to which of the provisions the consent relates.

Article 18. OBLIGATION NOT TO DEFEAT THE OBJECT AND PURPOSE OF A TREATY PRIOR TO ITS ENTRY INTO FORCE

A State is obliged to refrain from acts which would defeat the object and purpose of a treaty when:

(*a*) It has signed the treaty or has exchanged instruments constituting the treaty subject to ratification, acceptance or approval, until it shall have made its intention clear not to become a party to the treaty; or

(*b*) It has expressed its consent to be bound by the treaty, pending the entry into force of the treaty and provided that such entry into force is not unduly delayed.

SECTION 2. RESERVATIONS

Article 19. FORMULATION OF RESERVATIONS

A State may, when signing, ratifying, accepting, approving or acceding to a treaty, formulate a reservation unless:

(*a*) The reservation is prohibited by the treaty;

(*b*) The treaty provides that only specified reservations, which do not include the reservation in question, may be made; or

(*c*) In cases not falling under sub-paragraphs (*a*) and (*b*), the reservation is incompatible with the object and purpose of the treaty.

Article 20. ACCEPTANCE OF AND OBJECTION TO RESERVATIONS

1. A reservation expressly authorized by a treaty does not require any subsequent acceptance by the other contracting States unless the treaty so provides.

2. When it appears from the limited number of the negotiating States and the object and purpose of a treaty that the application of the treaty in its entirety between all the parties is an essential condition of the consent of each one to be bound by the treaty, a reservation requires acceptance by all the parties.

3. When a treaty is a constituent instrument of an international organization and unless it otherwise provides, a reservation requires the acceptance of the competent organ of that organization.

4. In cases not falling under the preceding paragraphs and unless the treaty otherwise provides:

(*a*) Acceptance by another contracting State of a reservation constitutes the reserving State a party to the treaty in relation to that other State if or when the treaty is in force for those States;

(*b*) An objection by another contracting State to a reservation does not preclude the entry into force of the treaty as between the objecting and reserving States unless a contrary intention is definitely expressed by the objecting State;

(*c*) An act expressing a State's consent to be bound by the treaty and containing a reservation is effective as soon as at least one other contracting State has accepted the reservation.

5. For the purposes of paragraphs 2 and 4 and unless the treaty otherwise provides, a reservation is considered to have been accepted by a State if it shall have raised no objection to the reservation by the end of a period of twelve months after it was notified of the reservation or by the date on which it expressed its consent to be bound by the treaty, whichever is later.

Article 21. LEGAL EFFECTS OF RESERVATIONS AND OF OBJECTIONS TO RESERVATIONS

1. A reservation established with regard to another party in accordance with articles 19, 20 and 23:

(*a*) Modifies for the reserving State in its relations with that other party the provisions of the treaty to which the reservation relates to the extent of the reservation; and

(*b*) Modifies those provisions to the same extent for that other party in its relations with the reserving State.

2. The reservation does not modify the provisions of the treaty for the other parties to the treaty *inter se*.

3. When a State objecting to a reservation has not opposed the entry into force of the treaty between itself and the reserving State, the provisions to which the reservation relates do not apply as between the two States to the extent of the reservation.

Article 22. WITHDRAWAL OF RESERVATIONS AND OF OBJECTIONS TO RESERVATIONS

1. Unless the treaty otherwise provides, a reservation may be withdrawn at any time and the consent of a State which has accepted the reservation is not required for its withdrawal.

2. Unless the treaty otherwise provides, an objection to a reservation may be withdrawn at any time.

3. Unless the treaty otherwise provides, or it is otherwise agreed:

(*a*) The withdrawal of a reservation becomes operative in relation to another contracting State only when notice of it has been received by that State;

(*b*) The withdrawal of an objection to a reservation becomes operative only when notice of it has been received by the State which formulated the reservation.

Article 23. PROCEDURE REGARDING RESERVATIONS

1. A reservation, an express acceptance of a reservation and an objection to a reservation must be formulated in writing and communicated to the contracting States and other States entitled to become parties to the treaty.

2. If formulated when signing the treaty subject to ratification, acceptance or approval, a reservation must be formally confirmed by the reserving State when expressing its consent to be bound by the treaty. In such a case the reservation shall be considered as having been made on the date of its confirmation.

3. An express acceptance of, or an objection to, a reservation made previously to confirmation of the reservation does not itself require confirmation.

4. The withdrawal of a reservation or of an objection to a reservation must be formulated in writing.

SECTION 3. ENTRY INTO FORCE AND PROVISIONAL APPLICATION OF TREATIES

Article 24. ENTRY INTO FORCE

1. A treaty enters into force in such manner and upon such date as it may provide or as the negotiating States may agree.

2. Failing any such provision or agreement, a treaty enters into force as soon as consent to be bound by the treaty has been established for all the negotiating States.

3. When the consent of a State to be bound by a treaty is established on a date after the treaty has come into force, the treaty enters into force for that State on that date, unless the treaty otherwise provides.

4. The provisions of a treaty regulating the authentication of its text, the establishment of the consent of States to be bound by the treaty, the manner or date of its entry into force, reservations, the functions of the depositary and other matters arising necessarily before the entry into force of the treaty apply from the time of the adoption of its text.

Article 25. PROVISIONAL APPLICATION

1. A treaty or a part of a treaty is applied provisionally pending its entry into force if:

(*a*) The treaty itself so provides; or

(*b*) The negotiating States have in some other manner so agreed.

2. Unless the treaty otherwise provides or the negotiating States have otherwise agreed, the provisional application of a treaty or a part of a treaty with respect to a State shall be terminated if that State notifies the other States between which the treaty is being applied provisionally of its intention not to become a party to the treaty.

PART III. OBSERVANCE, APPLICATION AND INTERPRETATION OF TREATIES

SECTION 1. OBSERVANCE OF TREATIES

Article 26. "PACTA SUNT SERVANDA"

Every treaty in force is binding upon the parties to it and must be performed by them in good faith.

Article 27. INTERNAL LAW AND OBSERVANCE OF TREATIES

A party may not invoke the provisions of its internal law as justification for its failure to perform a treaty. This rule is without prejudice to article 46.

SECTION 2. APPLICATION OF TREATIES

Article 28. NON-RETROACTIVITY OF TREATIES

Unless a different intention appears from the treaty or is otherwise established, its provisions do not bind a party in relation to any act or fact which took place or any situation which ceased to exist before the date of the entry into force of the treaty with respect to that party.

Article 29. TERRITORIAL SCOPE OF TREATIES

Unless a different intention appears from the treaty or is otherwise established, a treaty is binding upon each party in respect of its entire territory.

Article 30. APPLICATION OF SUCCESSIVE TREATIES RELATING TO THE SAME SUBJECT-MATTER

1. Subject to Article 103 of the Charter of the United Nations, the rights and obligations of States parties to successive treaties relating to the same subject-matter shall be determined in accordance with the following paragraphs.

2. When a treaty specifies that it is subject to, or that it is not to be considered as incompatible with, an earlier or later treaty, the provisions of that other treaty prevail.

3. When all the parties to the earlier treaty are parties also to the later treaty but the earlier treaty is not terminated or suspended in operation under article 59, the earlier treaty applies only to the extent that its provisions are compatible with those of the later treaty.

4. When the parties to the later treaty do not include all the parties to the earlier one:

(*a*) As between States parties to both treaties the same rule applies as in paragraph 3;

(*b*) As between a State party to both treaties and a State party to only one of the treaties, the treaty to which both States are parties governs their mutual rights and obligations.

5. Paragraph 4 is without prejudice to article 41, or to any question of the termination or suspension of the operation of a treaty under article 60 or to any ques-

tion of responsibility which may arise for a State from the conclusion or application of a treaty the provisions of which are incompatible with its obligations towards another State under another treaty.

SECTION 3. INTERPRETATION OF TREATIES

Article 31. GENERAL RULE OF INTERPRETATION

1. A treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose.

2. The context for the purpose of the interpretation of a treaty shall comprise, in addition to the text, including its preamble and annexes:

(*a*) Any agreement relating to the treaty which was made between all the parties in connexion with the conclusion of the treaty;

(*b*) Any instrument which was made by one or more parties in connexion with the conclusion of the treaty and accepted by the other parties as an instrument related to the treaty.

3. There shall be taken into account, together with the context:

(*a*) Any subsequent agreement between the parties regarding the interpretation of the treaty or the application of its provisions;

(*b*) Any subsequent practice in the application of the treaty which establishes the agreement of the parties regarding its interpretation;

(*c*) Any relevant rules of international law applicable in the relations between the parties.

4. A special meaning shall be given to a term if it is established that the parties so intended.

Article 32. SUPPLEMENTARY MEANS OF INTERPRETATION

Recourse may be had to supplementary means of interpretation, including the preparatory work of the treaty and the circumstances of its conclusion, in order to confirm the meaning resulting from the application of article 31, or to determine the meaning when the interpretation according to article 31:

(*a*) Leaves the meaning ambiguous or obscure; or

(*b*) Leads to a result which is manifestly absurd or unreasonable.

Article 33. INTERPRETATION OF TREATIES AUTHENTICATED IN TWO OR MORE LANGUAGES

1. When a treaty has been authenticated in two or more languages, the text is equally authoritative in each language, unless the treaty provides or the parties agree that, in case of divergence, a particular text shall prevail.

2. A version of the treaty in a language other than one of those in which the text was authenticated shall be considered an authentic text only if the treaty so provides or the parties so agree.

3. The terms of the treaty are presumed to have the same meaning in each authentic text.

4. Except where a particular text prevails in accordance with paragraph 1, when a comparison of the authentic texts discloses a difference of meaning which the application of articles 31 and 32 does not remove, the meaning which best reconciles the texts, having regard to the object and purpose of the treaty, shall be adopted.

SECTION 4. TREATIES AND THIRD STATES

Article 34. GENERAL RULE REGARDING THIRD STATES

A treaty does not create either obligations or rights for a third State without its consent.

Article 35. TREATIES PROVIDING FOR OBLIGATIONS FOR THIRD STATES

An obligation arises for a third State from a provision of a treaty if the parties to the treaty intend the provision to be the means of establishing the obligation and the third State expressly accepts that obligation in writing.

Article 36. TREATIES PROVIDING FOR RIGHTS FOR THIRD STATES

1. A right arises for a third State from a provision of a treaty if the parties to the treaty intend the provision to accord that right either to the third State, or to a group of States to which it belongs, or to all States, and the third State assents thereto. Its assent shall be presumed so long as the contrary is not indicated, unless the treaty otherwise provides.

2. A State exercising a right in accordance with paragraph 1 shall comply with the conditions for its exercise provided for in the treaty or established in conformity with the treaty.

Article 37. REVOCATION OR MODIFICATION OF OBLIGATIONS OR RIGHTS OF THIRD STATES

1. When an obligation has arisen for a third State in conformity with article 35, the obligation may be revoked or modified only with the consent of the parties to the treaty and of the third State, unless it is established that they had otherwise agreed.

2. When a right has arisen for a third State in conformity with article 36, the right may not be revoked or modified by the parties if it is established that the right was intended not to be revocable or subject to modification without the consent of the third State.

Article 38. RULES IN A TREATY BECOMING BINDING ON THIRD STATES THROUGH INTERNATIONAL CUSTOM

Nothing in articles 34 to 37 precludes a rule set forth in a treaty from becoming binding upon a third State as a customary rule of international law, recognized as such.

PART IV. AMENDMENT AND MODIFICATION OF TREATIES

Article 39. GENERAL RULE REGARDING THE AMENDMENT OF TREATIES

A treaty may be amended by agreement between the parties. The rules laid down in Part II apply to such an agreement except in so far as the treaty may otherwise provide.

Article 40. AMENDMENT OF MULTILATERAL TREATIES

1. Unless the treaty otherwise provides, the amendment of multilateral treaties shall be governed by the following paragraphs.

2. Any proposal to amend a multilateral treaty as between all the parties must be notified to all the contracting States, each one of which shall have the right to take part in:

(*a*) The decision as to the action to be taken in regard to such proposal;

(*b*) The negotiation and conclusion of any agreement for the amendment of the treaty.

3. Every State entitled to become a party to the treaty shall also be entitled to become a party to the treaty as amended.

4. The amending agreement does not bind any State already a party to the treaty which does not become a party to the amending agreement; article 30, paragraph 4(*b*), applies in relation to such State.

5. Any State which becomes a party to the treaty after the entry into force of the amending agreement shall, failing an expression of a different intention by that State:

(*a*) be considered as a party to the treaty as amended; and

(*b*) be considered as a party to the unamended treaty in relation to any party to the treaty not bound by the amending agreement.

Article 41. AGREEMENTS TO MODIFY MULTILATERAL TREATIES BETWEEN CERTAIN OF THE PARTIES ONLY

1. Two or more of the parties to a multilateral treaty may conclude an agreement to modify the treaty as between themselves alone if:

(*a*) The possibility of such a modification is provided for by the treaty; or

(*b*) The modification in question is not prohibited by the treaty and:

(i) Does not affect the enjoyment by the other parties of their rights under the treaty or the performance of their obligations;

(ii) Does not relate to a provision, derogation from which is incompatible with the effective execution of the object and purpose of the treaty as a whole.

2. Unless in a case falling under paragraph 1(*a*) the treaty otherwise provides, the parties in question shall notify the other parties of their intention to conclude the agreement and of the modification to the treaty for which it provides.

PART V. INVALIDITY, TERMINATION AND SUSPENSION OF THE OPERATION OF TREATIES

SECTION 1. GENERAL PROVISIONS

Article 42. VALIDITY AND CONTINUANCE IN FORCE OF TREATIES

1. The validity of a treaty or of the consent of a State to be bound by a treaty may be impeached only through the application of the present Convention.

2. The termination of a treaty, its denunciation or the withdrawal of a party, may take place only as a result of the application of the provisions of the treaty or of the present Convention. The same rule applies to suspension of the operation of a treaty.

Article 43. OBLIGATIONS IMPOSED BY INTERNATIONAL LAW INDEPENDENTLY OF A TREATY

The invalidity, termination or denunciation of a treaty, the withdrawal of a party from it, or the suspension of its operation, as a result of the application of the present Convention or of the provisions of the treaty, shall not in any way impair the duty of any State to fulfil any obligation embodied in the treaty to which it would be subject under international law independently of the treaty.

Article 44. SEPARABILITY OF TREATY PROVISIONS

1. A right of a party, provided for in a treaty or arising under article 56, to denounce, withdraw from or suspend the operation of the treaty may be exercised only with respect to the whole treaty unless the treaty otherwise provides or the parties otherwise agree.

2. A ground for invalidating, terminating, withdrawing from or suspending the operation of a treaty recognized in the present Convention may be invoked only with respect to the whole treaty except as provided in the following paragraphs or in article 60.

3. If the ground relates solely to particular clauses, it may be invoked only with respect to those clauses where:

(*a*) The said clauses are separable from the remainder of the treaty with regard to their application;

(*b*) It appears from the treaty or is otherwise established that acceptance of those clauses was not an essential basis of the consent of the other party or parties to be bound by the treaty as a whole; and

(*c*) Continued performance of the remainder of the treaty would not be unjust.

4. In cases falling under articles 49 and 50 the State entitled to invoke the fraud or corruption may do so with respect either to the whole treaty or, subject to paragraph 3, to the particular clauses alone.

5. In cases falling under articles 51, 52 and 53, no separation of the provisions of the treaty is permitted.

Article 45. LOSS OF A RIGHT TO INVOKE A GROUND FOR INVALIDATING, TERMINATING, WITHDRAWING FROM OR SUSPENDING THE OPERATION OF A TREATY

A State may no longer invoke a ground for invalidating, terminating, withdrawing from or suspending the operation of a treaty under articles 46 to 50 or articles 60 and 62 if, after becoming aware of the facts:

(*a*) It shall have expressly agreed that the treaty is valid or remains in force or continues in operation, as the case may be; or

(*b*) It must by reason of its conduct be considered as having acquiesced in the validity of the treaty or in its maintenance in force or in operation, as the case may be.

SECTION 2. INVALIDITY OF TREATIES

Article 46. PROVISIONS OF INTERNAL LAW REGARDING COMPETENCE TO CONCLUDE TREATIES

1. A State may not invoke the fact that its consent to be bound by a treaty has been expressed in violation of a provision of its internal law regarding competence to conclude treaties as invalidating its consent unless that violation was manifest and concerned a rule of its internal law of fundamental importance.

2. A violation is manifest if it would be objectively evident to any State conducting itself in the matter in accordance with normal practice and in good faith.

Article 47. SPECIFIC RESTRICTIONS ON AUTHORITY TO EXPRESS THE CONSENT OF A STATE

If the authority of a representative to express the consent of a State to be bound by a particular treaty has been made subject to a specific restriction, his omission to

observe that restriction may not be invoked as invalidating the consent expressed by him unless the restriction was notified to the other negotiating States prior to his expressing such consent.

Article 48. ERROR

1. A State may invoke an error in a treaty as invalidating its consent to be bound by the treaty if the error relates to a fact or situation which was assumed by that State to exist at the time when the treaty was concluded and formed an essential basis of its consent to be bound by the treaty.

2. Paragraph 1 shall not apply if the State in question contributed by its own conduct to the error or if the circumstances were such as to put that State on notice of a possible error.

3. An error relating only to the wording of the text of a treaty does not affect its validity; article 79 then applies.

Article 49. FRAUD

If a State has been induced to conclude a treaty by the fraudulent conduct of another negotiating State, the State may invoke the fraud as invalidating its consent to be bound by the treaty.

Article 50. CORRUPTION OF A REPRESENTATIVE OF A STATE

If the expression of a State's consent to be bound by a treaty has been procured through the corruption of its representative directly or indirectly by another negotiating State, the State may invoke such corruption as invalidating its consent to be bound by the treaty.

Article 51. COERCION OF A REPRESENTATIVE OF A STATE

The expression of a State's consent to be bound by a treaty which has been procured by the coercion of its representative through acts or threats directed against him shall be without any legal effect.

Article 52. COERCION OF A STATE BY THE THREAT OR USE OF FORCE

A treaty is void if its conclusion has been procured by the threat or use of force in violation of the principles of international law embodied in the Charter of the United Nations.

Article 53. TREATIES CONFLICTING WITH A PEREMPTORY NORM OF GENERAL INTERNATIONAL LAW ("JUS COGENS")

A treaty is void if, at the time of its conclusion, it conflicts with a peremptory norm of general international law. For the purposes of the present Convention, a peremptory norm of general international law is a norm accepted and recognized by the international community of States as a whole as a norm from which no derogation is permitted and which can be modified only by a subsequent norm of general international law having the same character.

SECTION 3. TERMINATION AND SUSPENSION OF THE OPERATION OF TREATIES

Article 54. TERMINATION OF OR WITHDRAWAL FROM A TREATY UNDER ITS PROVISIONS OR BY CONSENT OF THE PARTIES

The termination of a treaty or the withdrawal of a party may take place:

(*a*) In conformity with the provisions of the treaty; or

(*b*) At any time by consent of all the parties after consultation with the other contracting States.

Article 55. REDUCTION OF THE PARTIES TO A MULTILATERAL TREATY BELOW THE NUMBER NECESSARY FOR ITS ENTRY INTO FORCE

Unless the treaty otherwise provides, a multilateral treaty does not terminate by reason only of the fact that the number of the parties falls below the number necessary for its entry into force.

Article 56. DENUNCIATION OF OR WITHDRAWAL FROM A TREATY CONTAINING NO PROVISION REGARDING TERMINATION, DENUNCIATION OR WITHDRAWAL

1. A treaty which contains no provision regarding its termination and which does not provide for denunciation or withdrawal is not subject to denunciation or withdrawal unless:

(*a*) It is established that the parties intended to admit the possibility of denunciation or withdrawal; or

(*b*) A right of denunciation or withdrawal may be implied by the nature of the treaty.

2. A party shall give not less than twelve months' notice of its intention to denounce or withdraw from a treaty under paragraph 1.

Article 57. SUSPENSION OF THE OPERATION OF A TREATY UNDER ITS PROVISIONS OR BY CONSENT OF THE PARTIES

The operation of a treaty in regard to all the parties or to a particular party may be suspended:

(*a*) In conformity with the provisions of the treaty; or

(*b*) At any time by consent of all the parties after consultation with the other contracting States.

Article 58. SUSPENSION OF THE OPERATION OF A MULTILATERAL TREATY BY AGREEMENT BETWEEN CERTAIN OF THE PARTIES ONLY

1. Two or more parties to a multilateral treaty may conclude an agreement to suspend the operation of provisions of the treaty, temporarily and as between themselves alone, if:

(*a*) The possibility of such a suspension is provided for by the treaty; or

(*b*) The suspension in question is not prohibited by the treaty and:

(i) Does not affect the enjoyment by the other parties of their rights under the treaty or the performance of their obligations;

(ii) Is not incompatible with the object and purpose of the treaty.

2. Unless in a case falling under paragraph 1(*a*) the treaty otherwise provides, the parties in question shall notify the other parties of their intention to conclude the agreement and of those provisions of the treaty the operation of which they intend to suspend.

Article 59. TERMINATION OR SUSPENSION OF THE OPERATION OF A TREATY IMPLIED BY CONCLUSION OF A LATER TREATY

1. A treaty shall be considered as terminated if all the parties to it conclude a later treaty relating to the same subject-matter and:

(*a*) It appears from the later treaty or is otherwise established that the parties intended that the matter should be governed by that treaty; or

(*b*) The provisions of the later treaty are so far incompatible with those of the earlier one that the two treaties are not capable of being applied at the same time.

2. The earlier treaty shall be considered as only suspended in operation if it appears from the later treaty or is otherwise established that such was the intention of the parties.

Article 60. TERMINATION OR SUSPENSION OF THE OPERATION OF A TREATY AS A CONSEQUENCE OF ITS BREACH

1. A material breach of a bilateral treaty by one of the parties entitles the other to invoke the breach as a ground for terminating the treaty or suspending its operation in whole or in part.

2. A material breach of a multilateral treaty by one of the parties entitles:

(*a*) The other parties by unanimous agreement to suspend the operation of the treaty in whole or in part or to terminate it either:

(i) In the relations between themselves and the defaulting State, or

(ii) As between all the parties;

(*b*) A party specially affected by the breach to invoke it as a ground for suspending the operation of the treaty in whole or in part in the relations between itself and the defaulting State;

(*c*) Any party other than the defaulting State to invoke the breach as a ground for suspending the operation of the treaty in whole or in part with respect to itself if the treaty is of such a character that a material breach of its provisions by one party radically changes the position of every party with respect to the further performance of its obligations under the treaty.

3. A material breach of a treaty, for the purposes of this article, consists in:

(*a*) A repudiation of the treaty not sanctioned by the present Convention; or

(*b*) The violation of a provision essential to the accomplishment of the object or purpose of the treaty.

4. The foregoing paragraphs are without prejudice to any provision in the treaty applicable in the event of a breach.

5. Paragraphs 1 to 3 do not apply to provisions relating to the protection of the human person contained in treaties of a humanitarian character, in particular to provisions prohibiting any form of reprisals against persons protected by such treaties.

Article 61. SUPERVENING IMPOSSIBILITY OF PERFORMANCE

1. A party may invoke the impossibility of performing a treaty as a ground for terminating or withdrawing from it if the impossibility results from the permanent disappearance or destruction of an object indispensable for the execution of the treaty. If the impossibility is temporary, it may be invoked only as a ground for suspending the operation of the treaty.

2. Impossibility of performance may not be invoked by a party as a ground for terminating, withdrawing from or suspending the operation of a treaty if the impossibility is the result of a breach by that party either of an obligation under the treaty or of any other international obligation owed to any other party to the treaty.

Article 62. FUNDAMENTAL CHANGE OF CIRCUMSTANCES

1. A fundamental change of circumstances which has occurred with regard to those existing at the time of the conclusion of a treaty, and which was not foreseen by the parties, may not be invoked as a ground for terminating or withdrawing from the treaty unless:

(*a*) The existence of those circumstances constituted an essential basis of the consent of the parties to be bound by the treaty; and

(*b*) The effect of the change is radically to transform the extent of obligations still to be performed under the treaty.

2. A fundamental change of circumstances may not be invoked as a ground for terminating or withdrawing from a treaty:

(*a*) If the treaty establishes a boundary; or

(*b*) If the fundamental change is the result of a breach by the party invoking it either of an obligation under the treaty or of any other international obligation owed to any other party to the treaty.

3. If, under the foregoing paragraphs, a party may invoke a fundamental change of circumstances as a ground for terminating or withdrawing from a treaty it may also invoke the change as a ground for suspending the operation of the treaty.

Article 63. SEVERANCE OF DIPLOMATIC OR CONSULAR RELATIONS

The severance of diplomatic or consular relations between parties to a treaty does not affect the legal relations established between them by the treaty except in so far as the existence of diplomatic or consular relations is indispensable for the application of the treaty.

Article 64. EMERGENCE OF A NEW PEREMPTORY NORM OF GENERAL INTERNATIONAL LAW ("JUS COGENS")

If a new peremptory norm of general international law emerges, any existing treaty which is in conflict with that norm becomes void and terminates.

SECTION 4. PROCEDURE

Article 65. PROCEDURE TO BE FOLLOWED WITH RESPECT TO INVALIDITY, TERMINATION, WITHDRAWAL FROM OR SUSPENSION OF THE OPERATION OF A TREATY

1. A party which, under the provisions of the present Convention, invokes either a defect in its consent to be bound by a treaty or a ground for impeaching the validity of a treaty, terminating it, withdrawing from it or suspending its operation, must notify the other parties of its claim. The notification shall indicate the measure proposed to be taken with respect to the treaty and the reasons therefor.

2. If, after the expiry of a period which, except in cases of special urgency, shall not be less than three months after the receipt of the notification, no party has raised any objection, the party making the notification may carry out in the manner provided in article 67 the measure which it has proposed.

3. If, however, objection has been raised by any other party, the parties shall seek a solution through the means indicated in Article 33 of the Charter of the United Nations.

4. Nothing in the foregoing paragraphs shall affect the rights or obligations of the parties under any provisions in force binding the parties with regard to the settlement of disputes.

5. Without prejudice to article 45, the fact that a State has not previously made the notification prescribed in paragraph 1 shall not prevent it from making such notification in answer to another party claiming performance of the treaty or alleging its violation.

Article 66. PROCEDURES FOR JUDICIAL SETTLEMENT, ARBITRATION AND CONCILIATION

If, under paragraph 3 of article 65, no solution has been reached within a period of twelve months following the date on which the objection was raised, the following procedures shall be followed:

(*a*) Any one of the parties to a dispute concerning the application or the interpretation of article 53 or 64 may, by a written application, submit it to the International Court of Justice for a decision unless the parties by common consent agree to submit the dispute to arbitration;

(*b*) Any one of the parties to a dispute concerning the application or the interpretation of any of the other articles in Part V of the present Convention may set in motion the procedure specified in the Annex to the Convention by submitting a request to that effect to the Secretary-General of the United Nations.

Article 67. INSTRUMENTS FOR DECLARING INVALID, TERMINATING, WITHDRAWING FROM OR SUSPENDING THE OPERATION OF A TREATY

1. The notification provided for under article 65, paragraph 1 must be made in writing.

2. Any act declaring invalid, terminating, withdrawing from or suspending the operation of a treaty pursuant to the provisions of the treaty or of paragraphs 2 or 3 of article 65 shall be carried out through an instrument communicated to the other parties. If the instrument is not signed by the Head of State, Head of Government or Minister for Foreign Affairs, the representative of the State communicating it may be called upon to produce full powers.

Article 68. REVOCATION OF NOTIFICATIONS AND INSTRUMENTS PROVIDED FOR IN ARTICLES 65 AND 67

A notification or instrument provided for in article 65 or 67 may be revoked at any time before it takes effect.

SECTION 5. CONSEQUENCES OF THE INVALIDITY, TERMINATION OR SUSPENSION OF THE OPERATION OF A TREATY

Article 69. CONSEQUENCES OF THE INVALIDITY OF A TREATY

1. A treaty the invalidity of which is established under the present Convention is void. The provisions of a void treaty have no legal force.

2. If acts have nevertheless been performed in reliance on such a treaty:

(*a*) Each party may require any other party to establish as far as possible in their mutual relations the position that would have existed if the acts had not been performed;

(*b*) Acts performed in good faith before the invalidity was invoked are not rendered unlawful by reason only of the invalidity of the treaty.

3. In cases falling under articles 49, 50, 51 or 52, paragraph 2 does not apply with respect to the party to which the fraud, the act of corruption or the coercion is imputable.

4. In the case of the invalidity of a particular State's consent to be bound by a multilateral treaty, the foregoing rules apply in the relations between that State and the parties to the treaty.

Article 70. CONSEQUENCES OF THE TERMINATION OF A TREATY

1. Unless the treaty otherwise provides or the parties otherwise agree, the termination of a treaty under its provisions or in accordance with the present Convention:

(*a*) Releases the parties from any obligation further to perform the treaty;

(*b*) Does not affect any right, obligation or legal situation of the parties created through the execution of the treaty prior to its termination.

2. If a State denounces or withdraws from a multilateral treaty, paragraph 1 applies in the relations between that State and each of the other parties to the treaty from the date when such denunciation or withdrawal takes effect.

Article 71. CONSEQUENCES OF THE INVALIDITY OF A TREATY WHICH CONFLICTS WITH A PEREMPTORY NORM OF GENERAL INTERNATIONAL LAW

1. In the case of a treaty which is void under article 53 the parties shall:

(*a*) Eliminate as far as possible the consequences of any act performed in reliance on any provision which conflicts with the peremptory norm of general international law; and

(*b*) Bring their mutual relations into conformity with the peremptory norm of general international law.

2. In the case of a treaty which becomes void and terminates under article 64, the termination of the treaty:

(*a*) Releases the parties from any obligation further to perform the treaty;

(*b*) Does not affect any right, obligation or legal situation of the parties created through the execution of the treaty prior to its termination, provided that those rights, obligations or situations may thereafter be maintained only to the extent that their maintenance is not in itself in conflict with the new peremptory norm of general international law.

Article 72. CONSEQUENCES OF THE SUSPENSION OF THE OPERATION OF A TREATY

1. Unless the treaty otherwise provides or the parties otherwise agree, the suspension of the operation of a treaty under its provisions or in accordance with the present Convention:

(*a*) Releases the parties between which the operation of the treaty is suspended from the obligation to perform the treaty in their mutual relations during the period of the suspension;

(*b*) Does not otherwise affect the legal relations between the parties established by the treaty.

2. During the period of the suspension the parties shall refrain from acts tending to obstruct the resumption of the operation of the treaty.

PART VI. MISCELLANEOUS PROVISIONS

Article 73. CASES OF STATE SUCCESSION, STATE RESPONSIBILITY AND OUTBREAK OF HOSTILITIES

The provisions of the present Convention shall not prejudge any question that may arise in regard to a treaty from a succession of States or from the international responsibility of a State or from the outbreak of hostilities between States.

Article 74. DIPLOMATIC AND CONSULAR RELATIONS AND THE CONCLUSION OF TREATIES

The severance or absence of diplomatic or consular relations between two or more States does not prevent the conclusion of treaties between those States. The conclusion of a treaty does not in itself affect the situation in regard to diplomatic or consular relations.

Article 75. CASE OF AN AGGRESSOR STATE

The provisions of the present Convention are without prejudice to any obligation in relation to a treaty which may arise for an aggressor State in consequence of measures taken in conformity with the Charter of the United Nations with reference to that State's aggression.

PART VII. DEPOSITARIES, NOTIFICATIONS, CORRECTIONS AND REGISTRATION

Article 76. DEPOSITARIES OF TREATIES

1. The designation of the depositary of a treaty may be made by the negotiating States, either in the treaty itself or in some other manner. The depositary may be one or more States, an international organization or the chief administrative officer of the organization.

2. The functions of the depositary of a treaty are international in character and the depositary is under an obligation to act impartially in their performance. In particular, the fact that a treaty has not entered into force between certain of the parties or that a difference has appeared between a State and a depositary with regard to the performance of the latter's functions shall not affect that obligation.

Article 77. FUNCTIONS OF DEPOSITARIES

1. The functions of a depositary, unless otherwise provided in the treaty or agreed by the contracting States, comprise in particular:

(*a*) Keeping custody of the original text of the treaty and of any full powers delivered to the depositary;

(*b*) Preparing certified copies of the original text and preparing any further text of the treaty in such additional languages as may be required by the treaty and transmitting them to the parties and to the States entitled to become parties to the treaty;

(*c*) Receiving any signatures to the treaty and receiving and keeping custody of any instruments, notifications and communications relating to it;

(*d*) Examining whether the signature or any instrument, notification or communication relating to the treaty is in due and proper form and, if need be, bringing the matter to the attention of the State in question;

(*e*) Informing the parties and the States entitled to become parties to the treaty of acts, notifications and communications relating to the treaty;

(*f*) Informing the States entitled to become parties to the treaty when the number of signatures or of instruments of ratification, acceptance, approval or accession required for the entry into force of the treaty has been received or deposited;

(*g*) Registering the treaty with the Secretariat of the United Nations;

(*h*) Performing the functions specified in other provisions of the present Convention.

2. In the event of any difference appearing between a State and the depositary as to the performance of the latter's functions, the depositary shall bring the question to the attention of the signatory States and the contracting States or, where appropriate, of the competent organ of the international organization concerned.

Article 78. NOTIFICATIONS AND COMMUNICATIONS

Except as the treaty or the present Convention otherwise provide, any notification or communication to be made by any State under the present Convention shall:

(*a*) If there is no depositary, be transmitted direct to the States for which it is intended, or if there is a depositary, to the latter;

(*b*) Be considered as having been made by the State in question only upon its receipt by the State to which it was transmitted or, as the case may be, upon its receipt by the depositary;

(*c*) If transmitted to a depositary, be considered as received by the State for which it was intended only when the latter State has been informed by the depositary in accordance with article 77, paragraph 1(*e*).

Article 79. CORRECTION OF ERRORS IN TEXTS OR IN CERTIFIED COPIES OF TREATIES

1. Where, after the authentication of the text of a treaty, the signatory States and the contracting States are agreed that it contains an error, the error shall, unless they decide upon some other means of correction, be corrected:

(*a*) By having the appropriate correction made in the text and causing the correction to be initialled by duly authorized representatives;

(*b*) By executing or exchanging an instrument or instruments setting out the correction which it has been agreed to make; or

(*c*) By executing a corrected text of the whole treaty by the same procedure as in the case of the original text.

2. Where the treaty is one for which there is a depositary, the latter shall notify the signatory States and the contracting States of the error and of the proposal to correct it and shall specify an appropriate time-limit within which objection to the proposed correction may be raised. If, on the expiry of the time-limit:

(*a*) No objection has been raised, the depositary shall make and initial the correction in the text and shall execute a procès-verbal of the rectification of the text and communicate a copy of it to the parties and to the States entitled to become parties to the treaty;

(*b*) An objection has been raised, the depositary shall communicate the objection to the signatory States and to the contracting States.

3. The rules in paragraphs 1 and 2 apply also where the text has been authenticated in two or more languages and it appears that there is a lack of concordance which the signatory States and the contracting States agree should be corrected.

4. The corrected text replaces the defective text *ab initio*, unless the signatory States and the contracting States otherwise decide.

5. The correction of the text of a treaty that has been registered shall be notified to the Secretariat of the United Nations.

6. Where an error is discovered in a certified copy of a treaty, the depositary shall execute a procès-verbal specifying the rectification and communicate a copy of it to the signatory States and to the contracting States.

Article 80. REGISTRATION AND PUBLICATION OF TREATIES

1. Treaties shall, after their entry into force, be transmitted to the Secretariat of the United Nations for registration or filing and recording, as the case may be, and for publication.

2. The designation of a depositary shall constitute authorization for it to perform the acts specified in the preceding paragraph.

PART VIII. FINAL PROVISIONS

Article 81. SIGNATURE

The present Convention shall be open for signature by all States Members of the United Nations or of any of the specialized agencies or of the International Atomic Energy Agency or parties to the Statute of the International Court of Justice, and by any other State invited by the General Assembly of the United Nations to become a party to the Convention, as follows: until 30 November 1969, at the Federal Ministry for Foreign Affairs of the Republic of Austria, and subsequently, until 30 April 1970, at United Nations Headquarters, New York.

Article 82. RATIFICATION

The present Convention is subject to ratification. The instruments of ratification shall be deposited with the Secretary-General of the United Nations.

Article 83. ACCESSION

The present Convention shall remain open for accession by any State belonging to any of the categories mentioned in article 81. The instruments of accession shall be deposited with the Secretary-General of the United Nations.

Article 84. ENTRY INTO FORCE

1. The present Convention shall enter into force on the thirtieth day following the date of deposit of the thirty-fifth instrument of ratification or accession.

2. For each State ratifying or acceding to the Convention after the deposit of the thirty-fifth instrument of ratification or accession, the Convention shall enter into force on the thirtieth day after deposit by such State of its instrument of ratification or accession.

Article 85. AUTHENTIC TEXTS

The original of the present Convention, of which the Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary-General of the United Nations.

IN WITNESS WHEREOF the undersigned Plenipotentiaries, being duly authorized thereto by their respective Governments, have signed the present Convention.

DONE at Vienna, this twenty-third day of May, one thousand nine hundred and sixty-nine.

ANNEX

1. A list of conciliators consisting of qualified jurists shall be drawn up and maintained by the Secretary-General of the United Nations. To this end, every State which is a Member of the United Nations or a party to the present Convention shall be invited to nominate two conciliators, and the names of the persons so nominated shall constitute the list. The term of a conciliator, including that of any conciliator nominated to fill a casual vacancy, shall be five years and may be renewed. A conciliator whose term expires shall continue to fulfil any function for which he shall have been chosen under the following paragraph.

2. When a request has been made to the Secretary-General under article 66, the Secretary-General shall bring the dispute before a conciliation commission constituted as follows:

The State or States constituting one of the parties to the dispute shall appoint:

(*a*) One conciliator of the nationality of that State or of one of those States, who may or may not be chosen from the list referred to in paragraph 1; and

(*b*) One conciliator not of the nationality of that State or of any of those States, who shall be chosen from the list.

The State or States constituting the other party to the dispute shall appoint two conciliators in the same way. The four conciliators chosen by the parties shall be appointed within sixty days following the date on which the Secretary-General receives the request.

The four conciliators shall, within sixty days following the date of the last of their own appointments, appoint a fifth conciliator chosen from the list, who shall be chairman.

If the appointment of the chairman or of any of the other conciliators has not been made within the period prescribed above for such appointment, it shall be made by the Secretary-General within sixty days following the expiry of that period. The appointment of the chairman may be made by the Secretary-General either from the list or from the membership of the International Law Commission. Any of the periods within which appointments must be made may be extended by agreement between the parties to the dispute.

Any vacancy shall be filled in the manner prescribed for the initial appointment.

3. The Conciliation Commission shall decide its own procedure. The Commission, with the consent of the parties to the dispute, may invite any party to the treaty to submit to it its views orally or in writing. Decisions and recommendations of the Commission shall be made by a majority vote of the five members.

4. The Commission may draw the attention of the parties to the dispute to any measures which might facilitate an amicable settlement.

5. The Commission shall hear the parties, examine the claims and objections, and make proposals to the parties with a view to reaching an amicable settlement of the dispute.

6. The Commission shall report within twelve months of its constitution. Its report shall be deposited with the Secretary-General and transmitted to the parties to the dispute. The report of the Commission, including any conclusions stated therein regarding the facts or questions of law, shall not be binding upon the parties and it shall have no other character than that of recommendations submitted for the consideration of the parties in order to facilitate an amicable settlement of the dispute.

7. The Secretary-General shall provide the Commission with such assistance and facilities as it may require. The expenses of the Commission shall be borne by the United Nations.

For Afghanistan:
Pour l'Afghanistan :
阿富汗：
За Афганистан:
Por el Afganistán:

Subject to the declaration attached[1]
ABDUL H. TABIBI[2]

For Albania:
Pour l'Albanie :
阿尔巴尼亚：
За Албанию:
Por Albania:

For Algeria:
Pour l'Algérie :
阿尔及利亚：
За Алжир:
Por Argelia:

For Argentina:
Pour l'Argentine :
阿根廷：
За Аргентину:
Por la Argentina:

E. DE LA GUARDIA

For Australia:
Pour l'Australie :
澳大利亚：
За Австралию:
Por Australia:

[1] Avec une déclaration, dont texte joint en annexe.
[2] See p. 496 of this volume for the texts of the reservations and declarations made upon signature — Voir p. 496 du présent volume pour les textes des réserves et déclarations faites lors de la signature.

For Austria:
Pour l'Autriche :
奥地利：
За Австрию:
Por Austria:

For Barbados:
Pour la Barbade :
巴巴多斯：
За Барбадос:
Por Barbados:

GEORGE C. R. MOE

For Belgium:
Pour la Belgique :
比利时：
За Бельгию:
Por Bélgica:

For Bolivia:
Pour la Bolivie :
玻利维亚：
За Боливию:
Por Bolivia:

Sujeta a la declaración anexa[1]
J. ROMERO LOZA[2]

For Botswana:
Pour le Botswana :
博茨瓦纳：
За Ботсвану:
Por Botswana:

[1] Subject to the attached declaration — Avec une déclaration, dont texte joint en annexe.
[2] See p. 496 of this volume for the texts of the reservations and declarations made upon signature — Voir p. 496 du présent volume pour les textes des réserves et déclarations faites lors de la signature.

For Brazil:
Pour le Brésil :
巴西：
За Бразилию:
Por el Brasil:

G. NASCIMENTO E SILVA

For Bulgaria:
Pour la Bulgarie :
保加利亚：
За Болгарию:
Por Bulgaria:

For Burma:
Pour la Birmanie :
缅甸：
За Бирму:
Por Birmania:

For Burundi:
Pour le Burundi :
布隆迪：
За Бурунди:
Por Burundi:

For the Byelorussian Soviet Socialist Republic:
Pour la République socialiste soviétique de Biélorussie :
白俄罗斯苏维埃社会主义共和国：
За Белорусскую Советскую Социалистическую Республику:
Por la República Socialista Soviética de Bielorrusia:

For Cambodia:
Pour le Cambodge :
柬埔寨：
За Камбоджу:
Por Camboya:

SARIN CHHAK

For Cameroon:
Pour le Cameroun :
喀麥隆：
За Камерун:
Por el Camerún:

For Canada:
Pour le Canada :
加拿大：
За Канаду:
Por el Canadá:

For the Central African Republic:
Pour la République centrafricaine :
中非共和国：
За Центральноафриканскую Республику:
Por la República Centroafricana:

For Ceylon:
Pour le Ceylan :
錫蘭：
За Цейлон:
Por Ceilán:

For Chad:
Pour le Tchad :
乍得:
За Чад:
Por el Chad:

For Chile:
Pour le Chili :
智利:
За Чили:
Por Chile:

PEDRO J. RODRÍGUEZ
EDMUNDO VARGAS

For China:
Pour la Chine :
中国:
За Китай:
Por China:

LIU CHIEH
April 27, 1970

For Colombia:
Pour la Colombie :
哥伦比亚:
За Колумбию:
Por Colombia:

ANTONIO BAYONA
HUMBERTO RUIZ
J. J. CAICEDO PERDOMO

For the Congo (Brazzaville):
Pour le Congo (Brazzaville) :
刚果 (布拉薩市):
За Конго (Браззавиль):
Por el Congo (Brazzaville):

Sous réserve de ratification par mon pays[1]
S. BIKOUTHA

For the Congo (Democratic Republic of):
Pour le Congo (République démocratique du) :
剛果 (民主共和國):
За Демократическую Республику Конго:
Por el Congo (República Democrática de):

For Costa Rica:
Pour le Costa Rica :
哥斯达黎加:
За Коста-Рику:
Por Costa Rica:

Ad referendum y sujeto a las reservas anexas[2]
J. L. REDONDO GÓMEZ[3]

For Cuba:
Pour Cuba :
古巴:
За Кубу:
Por Cuba:

[1] Subject to ratification by my country.
[2] *Ad referendum* and subject to the attached reservations — *Ad referendum* et soumise aux réserves, dont texte joint en annexe.
[3] See p. 496 of this volume for the texts of the reservations and declarations made upon signature — Voir p. 496 du présent volume pour les textes des réserves et déclarations faites lors de la signature.

For Cyprus:
Pour Chypre :
塞浦路斯：
За Кипр:
Por Chipre:

For Czechoslovakia:
Pour la Tchécoslovaquie :
捷克斯洛伐克：
За Чехословакию:
Por Checoslovaquia:

For Dahomey:
Pour le Dahomey :
达荷美：
За Дагомею:
Por el Dahomey:

For Denmark:
Pour le Danemark :
丹麦：
За Данию:
Por Dinamarca:

OTTO BORCH
April 18, 1970

For the Dominican Republic:
Pour la République Dominicaine :
多米尼加共和国：
За Доминиканскую Республику:
Por la República Dominicana:

For Ecuador:
Pour l'Equateur :
厄瓜多尔：
За Эквадор:
Por el Ecuador:

Con la declaración que se anexo[1]
GONZALO ESCUDERO MOSCOSO[2]

For El Salvador:
Pour El Salvador :
萨尔瓦多：
За Сальвадор:
Por El Salvador:

R. GALINDO POHL
16 de febrero de 1970

For Equatorial Guinea:
Pour la Guinée équatoriale :
赤道几内亚：
За Экваториальную Гвинею:
Por Guinea Ecuatorial:

For Ethiopia:
Pour l'Ethiopie :
埃塞俄比亚：
За Эфиопию:
Por Etiopía:

KIFLE WODAJO
30 April 1970

[1] With the attached declaration — Avec une déclaration, dont texte joint en annexe.
[2] See p. 496 of this volume for the texts of the reservations and declarations made upon signature — Voir p. 496 du présent volume pour les textes des réserves et déclarations faites lors de la signature.

For the Federal Republic of Germany:
Pour la République fédérale d'Allemagne :
德意志聯邦共和國：
За Федеративную Республику Германии:
Por la República Federal de Alemania:

ALEXANDER BÖKER
30th April 1970

For Finland:
Pour la Finlande :
芬兰：
За Финляндию:
Por Finlandia:

ERIK CASTRÉN

For France:
Pour la France :
法国：
За Францию:
Por Francia:

For Gabon:
Pour le Gabon :
加蓬：
За Габон:
Por el Gabón:

For Gambia:
Pour la Gambie :
冈比亚：
За Гамбию:
Por Gambia:

For Ghana:
Pour le Ghana :
加纳：
За Гану:
Por Ghana:

EMMANUEL K. DADZIE
G. O. LAMPTEY

For Greece:
Pour la Grèce :
希腊：
За Грецию:
Por Grecia:

For Guatemala:
Pour le Guatemala :
危地马拉：
За Гватемалу:
Por Guatemala:

Ad referendum y sujeto a las reservas que constan en documento anexo[1]
ADOLFO MOLINA ORANTES[2]

For Guinea:
Pour la Guinée :
几内亚：
За Гвинею:
Por Guinea:

[1] *Ad referendum* and subject to the reservations contained in the attached document — *Ad referendum* et soumise aux réserves contenues dans le document ci-joint.

[2] See p. 496 of this volume for the texts of the reservations and declarations made upon signature — Voir p. 496 du présent volume pour les textes des réserves et déclarations faites lors de la signature.

For Guyana:
Pour la Guyane :
圭亚那：
За Гайану:
Por Guyana:

JOHN CARTER

For Haiti:
Pour Haïti :
海地：
За Гаити:
Por Haití:

For the Holy See:
Pour le Saint-Siège :
教廷：
За Святейший Престол:
Por la Santa Sede:

OPILIO ROSSI
30 September 1969

For Honduras:
Pour le Honduras :
洪都拉斯：
За Гондурас:
Por Honduras:

MARIO CARÍAS ZAPATA

For Hungary:
Pour la Hongrie :
匈牙利：
За Венгрию:
Por Hungría:

For Iceland:
Pour l'Islande :
冰岛：
За Исландию:
Por Islandia:

For India:
Pour l'Inde :
印度：
За Индию:
Por la India:

For Indonesia:
Pour l'Indonésie :
印度尼西亚：
За Индонезию:
Por Indonesia:

For Iran:
Pour l'Iran :
伊朗：
За Иран:
Por el Irán:

A. MATINE-DAFTARY

For Iraq:
Pour l'Irak :
伊拉克：
За Ирак:
Por el Irak:

For Ireland:
Pour l'Irlande :
爱尔兰：
За Ирландию:
Por Irlanda:

For Israel:
Pour Israël :
以色列：
За Израиль:
Por Israel:

For Italy:
Pour l'Italie :
意大利：
За Италию:
Por Italia:

PIERO VINCI
22 April 1970

For the Ivory Coast:
Pour la Côte-d'Ivoire :
象牙海岸：
За Берег Слоновой Кости:
Por la Costa de Marfil:

LUCIEN YAPOBI
23 July 1969

For Jamaica:
Pour la Jamaïque :
牙买加：
За Ямайку:
Por Jamaica:

L. B. FRANCIS
K. RATTRAY

For Japan:
Pour le Japon :
日本：
За Японию:
Por el Japón:

For Jordan:
Pour la Jordanie :
约旦：
За Иорданию:
Por Jordania:

For Kenya:
Pour le Kenya :
肯尼亚:
За Кению:
Por Kenya:

I. S. Bhoi

For Kuwait:
Pour le Koweït :
科威特：
За Кувейт:
Por Kuwait:

For Laos:
Pour le Laos :
老挝：
За Лаос:
Por Laos:

For Lebanon:
Pour le Liban :
黎巴嫩：
За Ливан:
Por el Líbano:

For Lesotho:
Pour le Lesotho :
莱索托：
За Лесото:
Por Lesotho:

For Liberia:
Pour le Libéria :
利比里亚：
За Либерию:
Por Liberia:

NELSON BRODERICK

For Libya:
Pour la Libye :
利比亞：
За Ливию:
Por Libia:

For Liechtenstein:
Pour le Liechtenstein :
列支敦士登：
За Лихтенштейн:
Por Liechtenstein:

For Luxembourg:
Pour le Luxembourg :
卢森堡：
За Люксембург:
Por Luxemburgo:

GASTON THORN
4 septembre 1969

For Madagascar:
Pour Madagascar :
马达加斯加：
За Мадагаскар:
Por Madagascar:

Ad referendum
B. RAZAFINTSEHENO

For Malawi:
Pour le Malawi :
马拉维：
За Малави:
Por Malawi:

For Malaysia:
Pour la Malaisie :
马来西亚：
За Малайскую Федерацию:
Por Malasia:

For the Maldive Islands:
Pour les îles Maldives :
馬爾代夫羣島：
За Мальдивские острова:
Por las Islas Maldivas:

For Mali:
Pour le Mali :
马里：
За Мали:
Por Malí:

For Malta:
Pour Malte :
马耳他：
За Мальту:
Por Malta:

For Mauritania:
Pour la Mauritanie :
毛里塔尼亚：
За Мавританию:
Por Mauritania:

For Mauritius:
Pour Maurice :
毛里求斯：
За Маврикий:
Por Mauricio:

For Mexico:
Pour le Mexique :
墨西哥：
За Мексику:
Por México:

EDUARDO SUÁREZ

For Monaco:
Pour Monaco :
摩纳哥 :
За Монако:
Por Mónaco:

For Mongolia:
Pour la Mongolie :
蒙古 :
За Монголию:
Por Mongolia:

For Morocco:
Pour le Maroc :
摩洛哥 :
За Марокко:
Por Marruecos:

Sous réserve de la déclaration ci-jointe[1]
TAOUFIQ KABBAJ[2]

For Nauru:
Pour Nauru :
瑙鲁 :
За Науру:
Por Nauru:

For Nepal:
Pour le Népal :
尼泊尔 :
За Непал:
Por Nepal:

PRADUMNA LAL RAJBHANDARY

[1] Subject to the attached declaration.
[2] See p. 496 of this volume for the texts of the reservations and declarations made upon signature — Voir p. 496 du présent volume pour les textes des réserves et déclarations faites lors de la signature.

For the Netherlands:
Pour les Pays-Bas :
荷兰：
За Нидерланды:
Por los Países Bajos:

For New Zealand:
Pour la Nouvelle-Zélande :
新西兰：
За Новую Зеландию:
Por Nueva Zelandia:

JOHN V. SCOTT
29 April 1970

For Nicaragua:
Pour le Nicaragua :
尼加拉瓜：
За Никарагуа:
Por Nicaragua:

For the Niger:
Pour le Niger :
尼日尔：
За Нигер:
Por el Níger:

For Nigeria:
Pour la Nigéria :
尼日利亚：
За Нигерию:
Por Nigeria:

T. O. ELIAS

For Norway:
Pour la Norvège :
挪威：
За Норвегию:
Por Noruega:

For Pakistan:
Pour le Pakistan :
巴基斯坦：
За Пакистан:
Por el Pakistán:

A. SHAHI
29 April, 1970

For Panama:
Pour le Panama :
巴拿马：
За Панаму:
Por Panamá:

For Paraguay:
Pour le Paraguay :
巴拉圭：
За Парагвай:
Por el Paraguay:

For Peru:
Pour le Pérou :
秘鲁：
За Перу:
Por el Perú:

LUIS ALVARADO GARRIDO
JUAN JOSÉ CALLE

For the Philippines:
Pour les Philippines :
菲律宾：
За Филиппины:
Por Filipinas:

ROBERTO CONCEPCIÓN

For Poland:
Pour la Pologne :
波兰：
За Польшу:
Por Polonia:

For Portugal:
Pour le Portugal :
葡萄牙：
За Португалию:
Por Portugal:

For the Republic of Korea:
Pour la République de Corée :
大韩民国：
За Корейскую Республику:
Por la República de Corea:

YANG SOO YU
27 November 1969

For the Republic of Viet-Nam:
Pour la République du Viet-Nam :
越南共和国：
За Республику Вьетнам:
Por la República de Viet-Nam:

For Romania:
Pour la Roumanie :
罗马尼亚：
За Румынию:
Por Rumania:

For Rwanda:
Pour le Rwanda :
卢旺达：
За Руанду:
Por Rwanda:

For San Marino:
Pour Saint-Marin :
圣马力诺：
За Сан-Марино:
Por San Marino:

For Saudi Arabia:
Pour l'Arabie Saoudite :
沙特阿拉伯：
За Саудовскую Аравию:
Por Arabia Saudita:

For Senegal:
Pour le Sénégal :
塞内加尔：
За Сенегал:
Por el Senegal:

For Sierra Leone:
Pour le Sierra Leone :
塞拉勒窝内:
За Сьерра-Леоне:
Por Sierra Leona:

For Singapore:
Pour Singapour :
新加坡:
За Сингапур:
Por Singapur:

For Somalia:
Pour la Somalie :
索马里:
За Сомали:
Por Somalia:

For South Africa:
Pour l'Afrique du Sud :
南非:
За Южную Африку:
Por Sudáfrica:

For Southern Yemen:
Pour le Yémen du Sud :
南也門:
За Южный Йемен:
Por el Yemen Meridional:

For Spain:
Pour l'Espagne :
西班牙：
За Испанию:
Por España:

For the Sudan:
Pour le Soudan :
苏丹：
За Судан:
Por el Sudán:

AHMED SALAH BUKHARI

For Swaziland:
Pour le Souaziland :
斯威士兰：
За Свазиленд:
Por Swazilandia:

For Sweden:
Pour la Suède :
瑞典：
За Швецию:
Por Suecia:

TORSTEN ÖRN
23 April 1970

For Switzerland:
Pour la Suisse :
瑞士：
За Швейцарию:
Por Suiza:

For Syria:
Pour la Syrie :
叙利亚：
За Сирию:
Por Siria:

For Thailand:
Pour la Thaïlande :
泰国：
За Таиланд:
Por Tailandia:

For Togo:
Pour le Togo :
多哥：
За Того:
Por el Togo:

For Trinidad and Tobago:
Pour la Trinité-et-Tobago :
特立尼达和多巴哥：
За Тринидад и Тобаго:
Por Trinidad y Tabago:

T. BADEN-SEMPER

For Tunisia:
Pour la Tunisie :
突尼斯：
За Тунис:
Por Túnez:

For Turkey:
Pour la Turquie :
土耳其：
За Турцию:
Por Turquía:

For Uganda:
Pour l'Ouganda :
乌干达：
За Уганду:
Por Uganda:

For the Ukrainian Soviet Socialist Republic:
Pour la République socialiste soviétique d'Ukraine :
乌克兰苏维埃社会主义共和国：
За Украинскую Советскую Социалистическую Республику:
Por la República Socialista Soviética de Ucrania:

For the Union of Soviet Socialist Republics:
Pour l'Union des Républiques socialistes soviétiques :
苏维埃社会主义共和国联盟：
За Союз Советских Социалистических Республик:
Por la Unión de Repúblicas Socialistas Soviéticas:

For the United Arab Republic:
Pour la République arabe unie :
阿拉伯聯合共和國：
За Объединенную Арабскую Республику:
Por la República Arabe Unida:

For the United Kingdom of Great Britain and Northern Ireland:
Pour le Royaume-Uni de Grande-Bretagne et d'Irlande du Nord :
大不列颠及北爱尔兰联合王国:
За Соединенное Королевство Великобритании и Северной Ирландии:
Por el Reino Unido de Gran Bretaña e Irlanda del Norte:

Subject to the declaration, the text of which is attached[1]
CARADON[2]
20 April 1970

For the United Republic of Tanzania:
Pour la République-Unie de Tanzanie :
坦桑尼亚联合共和国:
За Объединенную Республику Танзания:
Por la República Unida de Tanzanía:

For the United States of America:
Pour les Etats-Unis d'Amérique :
美利坚合众国:
За Соединенные Штаты Америки:
Por los Estados Unidos de América:

RICHARD D. KEARNEY
24 April 1970

JOHN R. STEVENSON
24 April 1970

For the Upper Volta:
Pour la Haute-Volta :
上沃尔特:
За Верхнюю Вольту:
Por el Alto Volta:

[1] Avec une déclaration, dont texte joint en annexe.
[2] See p. 496 of this volume for the texts of the reservations and declarations made upon signature – Voir p. 496 du présent volume pour les textes des réserves et déclarations faites lors de la signature.

For Uruguay:
Pour l'Uruguay :
乌拉圭:
За Уругвай:
Por el Uruguay:

EDUARDO JIMÉNEZ DE ARÉCHAGA
ALVARO ALVAREZ

For Venezuela:
Pour le Venezuela :
委内瑞拉:
За Венесуэлу:
Por Venezuela:

For Western Samoa:
Pour le Samoa-Occidental :
西萨摩亚:
За Западное Самоа:
Por Samoa Occidental:

For Yemen:
Pour le Yémen :
也门:
За Йемен:
Por el Yemen:

For Yugoslavia:
Pour la Yougoslavie :
南斯拉夫:
За Югославию:
Por Yugoslavia:

ALEKSANDAR JELIĆ

For Zambia:
Pour la Zambie :
赞比亚:
За Замбию:
Por Zambia:

LISHOMWA MUUKA

RESERVATIONS AND DECLARATIONS MADE UPON SIGNATURE

AFGHANISTAN

"Afghanistan's understanding of article 62 (fundamental change of circumstances) is as follows:

"Sub-paragraph 2 (*a*) of this article does not cover unequal and illegal treaties, or any treaties which were contrary to the principle of self-determination. This view was also supported by the Expert Consultant in his statement of 11 May 1968 in the Committee of the Whole and on 14 May 1969 (doc. A/CONF.39/L.40) to the Conference."

RÉSERVES ET DÉCLARATIONS FAITES LORS DE LA SIGNATURE

AFGHANISTAN

[TRADUCTION — TRANSLATION]

L'Afghanistan interprète l'article 62 (Changement fondamental de circonstances) de la manière suivante :

L'alinéa *a* du paragraphe 2 ne s'applique pas dans le cas de traités inégaux ou illégaux, ni dans le cas de tout autre traité contraire au principe de l'autodétermination. Cette interprétation est celle qui a été soutenue par l'Expert consultant dans sa déclaration du 11 mai 1968 devant la Commission plénière et dans la communication du 14 mai 1969 (A/CONF.39/L.40) qu'il a adressée à la Conférence.

BOLIVIA

[SPANISH TEXT — TEXTE ESPAGNOL]

"1. La imperfección de la Convención de Viena sobre el derecho de los tratados posterga la realización de las aspiraciones de la humanidad.

"2. No obstante lo anterior, los preceptos aprobados por la Convención constituyen avances significativos inspirados en principios de justicia internacional que Bolivia ha sostenido tradicionalmente."

[TRANSLATION]

1. The shortcomings of the Vienna Convention on the Law of Treaties are such as to postpone the realization of the aspirations of mankind.

2. Nevertheless, the rules endorsed by the Convention do represent significant advances, based on the principles of international justice which Bolivia has traditionally supported.

BOLIVIE

[TRADUCTION]

1. L'imperfection de la Convention de Vienne sur le droit des traités retarde la réalisation des aspirations de l'humanité.

2. Néanmoins, les normes que consacre la Convention marquent d'importants progrès fondés sur des principes de justice internationale que la Bolivie a traditionnellement défendus.

COSTA RICA *COSTA RICA*

[SPANISH TEXT — TEXTE ESPAGNOL]

"1. En relación a los artículos 11 y 12 la delegación de Costa Rica hace la reserva de que el sistema jurídico constitucional de ese país no autoriza ninguna forma de consentimiento que no esté sujeto a ratificación de la Asamblea Legislativa.

"2. En cuanto al artículo 25 hace la reserva de que la Constitución Política de dicho país tampoco admite la entrada en vigor provisional de los tratados.

"3. En cuanto al artículo 27 interpreta que se refiere al derecho secundario, no así a las disposiciones de la Constitución Política.

"4. En relación al artículo 38 interpreta que una norma consuetudinaria de derecho internacional general no privará sobre ninguna norma del sistema interamericano del cual considera supletoria la presente Convención."

[TRANSLATION]

1. With regard to articles 11 and 12, the delegation of Costa Rica wishes to make a reservation to the effect that the Costa Rican system of constitutional law does not authorize any form of consent which is not subject to ratification by the Legislative Assembly.

2. With regard to article 25, it wishes to make a reservation to the effect that the Political Constitution of Costa Rica does not permit the provisional application of treaties, either.

3. With regard to article 27, it interprets this article as referring to secondary law and not to the provisions of the Political Constitution.

4. With regard to article 38, its interpretation is that no customary rule of general international law shall take precedence over any rule of the Inter-American System to which, in its view, this Convention is supplementary.

[TRADUCTION]

1. En ce qui concerne les articles 11 et 12, la délégation du Costa Rica formule la réserve suivante : en matière constitutionnelle, le système juridique de ce pays n'autorise aucune forme de consentement qui ne soit sujette à ratification par l'Assemblée législative.

2. En ce qui concerne l'article 25, la délégation du Costa Rica formule la réserve suivante : la Constitution politique de ce pays n'admet pas non plus l'entrée en vigueur provisoire des traités.

3. La délégation du Costa Rica interprète l'article 27 comme visant les lois ordinaires mais non les dispositions de la Constitution politique.

4. La délégation du Costa Rica interprète l'article 38 de la manière suivante : une règle coutumière du droit international général ne prévaudra sur aucune règle du système interaméricain, au regard duquel la présente Convention revêt, à son avis, un caractère supplémentaire.

ECUADOR *ÉQUATEUR*

[SPANISH TEXT — TEXTE ESPAGNOL]

"El Ecuador, al firmar la presente Convención, no ha creído necesario formular reserva alguna al artículo 4 de este instrumento porque entiende que, entre las normas comprendidas en la primera parte del artículo 4, se encuentra el principio de solución

pacífica de controversias, establecido en el Artículo 2, párrafo 3, de la Carta de las Naciones Unidas, cuyo carácter de *jus cogens* confiere a esa norma valor imperativo universal.

"El Ecuador considera asimismo que la primera parte del artículo 4, por tanto, es aplicable a los tratados existentes.

"Deja en claro en esta forma que dicho artículo recoge el principio inconcuso de que, cuando la Convención codifica normas *lex lata*, éstas, siendo normas preexistentes, pueden invocarse y aplicarse a tratados suscritos antes de la vigencia de esta Convención, la cual constituye su instrumento codificador."

[TRANSLATION]

In signing this Convention, Ecuador has not considered it necessary to make any reservation in regard to article 4 of the Convention because it understands that the rules referred to in the first part of article 4 include the principle of the peaceful settlement of disputes, which is set forth in Article 2, paragraph 3, of the Charter of the United Nations and which, as *jus cogens*, has universal and mandatory force.

Ecuador also considers that the first part of article 4 is applicable to existing treaties.

It wishes to place on record, in this form, its view that the said article 4 incorporates the indisputable principle that, in cases where the Convention codifies rules of *lex lata*, these rules, as pre-existing rules, may be invoked and applied to treaties signed before the entry into force of this Convention, which is the instrument codifying the rules.

[TRADUCTION]

En signant la présente Convention, l'Equateur n'a pas jugé nécessaire de formuler une réserve quelconque au sujet de l'article 4 de cet instrument, car il considère qu'au nombre des règles auxquelles se réfère la première partie de cet article figure le principe du règlement pacifique des différends, énoncé au paragraphe 3 de l'Article 2 de la Charte des Nations Unies, dont le caractère de *jus cogens* lui confère une valeur impérative universelle.

De même, l'Equateur considère également que la première partie de l'article 4 est applicable aux traités existants.

Il tient à préciser à cette occasion que ledit article s'appuie sur le principe incontestable selon lequel, lorsque la Convention codifie des règles relevant de la *lex lata*, ces règles, du fait qu'elles sont préexistantes, peuvent être invoquées et appliquées au regard de traités conclus avant l'entrée en vigueur de ladite Convention, laquelle constitue l'instrument les ayant codifiées.

GUATEMALA

GUATEMALA

[SPANISH TEXT — TEXTE ESPAGNOL]

"La delegación de Guatemala, al suscribir la Convención de Viena sobre el derecho de los tratados, formula las siguientes reservas:

"I. Guatemala no puede aceptar disposición alguna de la presente Convención que menoscabe sus derechos y su reclamación sobre el Territorio de Belice.

"II. Guatemala no aplicará los artículos 11, 12, 25 y 66 en lo que contravinieren preceptos de la Constitución de la República.

"III. Guatemala aplicará lo dispuesto en el artículo 38 solamente en aquellos casos en que lo considere conveniente para los intereses del país."

[TRANSLATION]

The delegation of Guatemala, in signing the Vienna Convention on the Law of Treaties, wishes to make the following reservations:

I. Guatemala cannot accept any provision of this Convention which would prejudice its rights and its claim to the Territory of Belize.

II. Guatemala will not apply articles 11, 12, 25 and 66 in so far as they are contrary to the provisions of the Constitution of the Republic.

III. Guatemala will apply the provision contained in article 38 only in cases where it considers that it is in the national interest to do so.

[TRADUCTION]

En signant la Convention de Vienne sur le droit des traités, la délégation du Guatemala formule les réserves suivantes :

I. Le Guatemala ne peut accepter aucune disposition de la présente Convention qui porte atteinte à ses droits et à sa revendication sur le territoire de Belize.

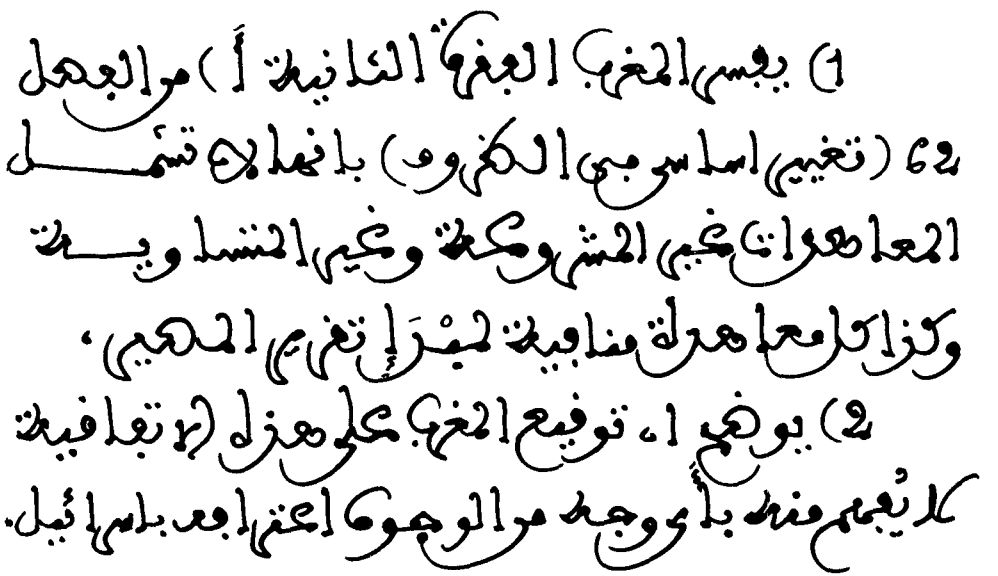
II. Le Guatemala n'appliquera pas les dispositions des articles 11, 12, 25 et 66, dans la mesure où elles contreviendraient aux principes consacrés dans la Constitution de la République.

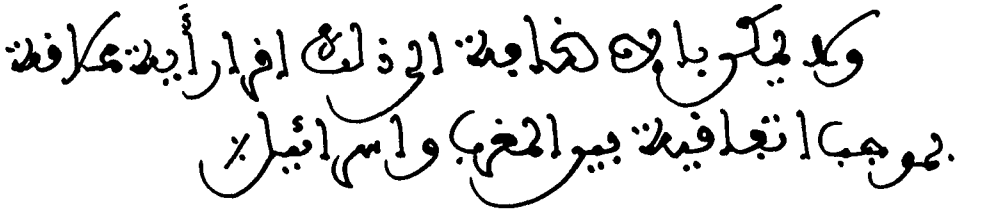
III. Le Guatemala n'appliquera les dispositions de l'article 38 que dans le cas où il considérera que cela sert les intérêts du pays.

MOROCCO

MAROC

[ARABIC TEXT — TEXTE ARABE]





[TRANSLATION — TRADUCTION]

1. Morocco interprets paragraph 2 (*a*) of article 62 (Fundamental change of circumstances) as not applying to unlawful or inequitable treaties, or to any treaty contrary to the principle of self-determination. Morocco's views on paragraph 2 (*a*) were supported by the Expert Consultant in his statements in the Committee of the Whole on 11 May 1968 and before the Conference in plenary on 14 May 1969 (see document A/CONF.39/L.40).

2. It shall be understood that Morocco's signature of this Convention does not in any way imply that it recognized Israel. Furthermore, no treaty relationships will be established between Morocco and Israel.

«1. Le Maroc interprète le paragraphe 2, *a*, de l'article 62 (Changement fondamental de circonstances) comme ne couvrant pas les traités illicites et inégaux ainsi que tout traité contraire au principe de l'autodétermination. Le point de vue du Maroc sur le paragraphe 2, *a*, a été soutenu par l'Expert consultant dans son intervention du 11 mai 1968 en Commission plénière ainsi que le 14 mai 1969 à la Conférence plénière (document A/CONF.39/L.40).

«2. Il est entendu que la signature par le Maroc de la présente Convention ne signifie en aucune façon qu'il reconnaisse Israël. En outre, aucune relation conventionnelle ne sera établie entre le Maroc et Israël.»

UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

"In signing the Vienna Convention on the Law of Treaties, the Government of the United Kingdom of Great Britain and Northern Ireland declare their understanding that nothing in article 66 of the Convention is intended to oust the jurisdiction of the International Court of Justice where such jurisdiction exists under any provisions in force binding the parties with regard to the settlement of disputes. In particular, and in relation to States parties to the Vienna Convention which accept as compulsory the jurisdiction of the International Court of Jus-

ROYAUME-UNI DE GRANDE-BRETAGNE ET D'IRLANDE DU NORD

[TRADUCTION — TRANSLATION]

Le Gouvernement du Royaume-Uni de Grande-Bretagne et d'Irlande du Nord déclare considérer qu'aucune disposition de l'article 66 de ladite Convention ne vise à écarter la juridiction de la Cour internationale de Justice lorsque cette juridiction découle de clauses en vigueur entre les parties, concernant le règlement des différends et ayant force obligatoire à leur égard. Le Gouvernement du Royaume-Uni déclare notamment, au regard des Etats parties à la Convention de Vienne qui acceptent comme obligatoire la juridiction de la

tice, the Government of the United Kingdom declare that they will not regard the provisions of sub-paragraph (*b*) of article 66 of the Vienna Convention as providing 'some other method of peaceful settlement' within the meaning of sub-paragraph (i) (*a*) of the Declaration of the Government of the United Kingdom accepting as compulsory the jurisdiction of the International Court of Justice which was deposited with the Secretary-General of the United Nations on the 1st of January, 1969.[1]

"The Government of the United Kingdom, while reserving their position for the time being with regard to the other declarations and reservations made by various States on signing the Convention, consider it necessary to state that the United Kingdom does not accept that Guatemala has any rights or any valid claim in respect of the territory of British Honduras."

Cour internationale de Justice, qu'il ne considérera pas les dispositions de l'alinéa *b* de l'article 66 de la Convention de Vienne comme fournissant «un autre mode de règlement pacifique», au sens du paragraphe i, *a*, de la Déclaration, déposée auprès du Secrétaire général de l'Organisation des Nations Unies le 1er janvier 1969, par laquelle le Gouvernement du Royaume-Uni a accepté comme obligatoire la juridiction de la Cour internationale de Justice[1].

Le Gouvernement du Royaume-Uni, tout en réservant pour le moment sa position vis-à-vis des autres déclarations et réserves faites par divers Etats lors de la signature de la Convention par ces derniers, juge nécessaire de déclarer que le Royaume-Uni ne reconnaît au Guatemala aucun droit ni titre légitime de réclamation en ce qui concerne le territoire du Honduras britannique.

RESERVATIONS AND DECLARATIONS MADE UPON RATIFICATION OR ACCESSION (*a*)

ARGENTINA

[SPANISH TEXT — TEXTE ESPAGNOL]

"*a*) La República Argentina no considera aplicable a su respecto la norma contenida en el artículo 45, apartado *b*, por cuanto la misma consagra la renuncia anticipada de derechos".

"*b*) La República Argentina no acepta que un cambio fundamental en las circunstancias ocurrido con respecto a las existentes en el momento de la celebración de un tratado y que no fue previsto por las partes pueda alegarse como causa para dar por terminado el tratado o retirarse de él y, además, objeta las reservas formuladas por Afganistán, Marruecos y Siria al artículo 62, párrafo 2, apartado *a*, y todas las reservas del mismo alcance que la de los Estados mencionados que se presenten en el futuro sobre el artículo 62".

[TRANSLATION]

(*a*) The Argentine Republic does not regard the rule contained in article 45 (*b*) as applicable to it inasmuch as the rule in question provides for the renunciation of rights in advance.

[1] United Nations, *Treaty Series*, vol. 654, p. 335.

RÉSERVES ET DÉCLARATIONS FAITES LORS DE LA RATIFICATION OU DE L'ADHÉSION (*a*)

ARGENTINE

[TRADUCTION]

a) La République argentine ne considère pas que la règle énoncée à l'article 45, *b*, lui est applicable dans la mesure où celle-ci prévoit la renonciation anticipée à certains droits.

[1] Nations Unies, *Recueil des Traités*, vol. 654, p. 335.

(*b*) The Argentine Republic does not accept the idea that a fundamental change of circumstances which has occurred with regard to those existing at the time of the conclusion of a treaty, and which was not foreseen by the parties, may be invoked as a ground for terminating or withdrawing from the treaty; moreover, it objects to the reservations made by Afghanistan, Morocco and Syria with respect to article 62, paragraph 2 (*a*), and to any reservations to the same effect as those of the States referred to which may be made in the future with respect to article 62.

b) La République argentine n'admet pas qu'un changement fondamental de circonstances qui s'est produit par rapport à celles qui existaient au moment de la conclusion du traité et qui n'avait pas été prévu par les parties puisse être invoqué comme motif pour mettre fin au traité ou pour s'en retirer; de plus, elle s'élève contre les réserves formulées par l'Afghanistan, le Maroc et la Syrie au sujet du paragraphe 2, *a*, de l'article 62 et contre toutes autres réserves de même effet que celles des Etats susmentionnés qui pourraient être formulées à l'avenir au sujet de l'article 62.

[SPANISH TEXT — TEXTE ESPAGNOL]

"La aplicación de la presente Convención a territorios cuya soberanía fuera discutida entre dos o más Estados que sean parte o no de la misma, no podrá ser interpretada como alteración, renuncia o abandono de la posición que cada uno ha sostenido hasta el presente".

[TRANSLATION]

The application of this Convention to territories whose sovereignty is a subject of dispute between two or more States, whether or not they are parties to it, cannot be deemed to imply a modification, renunciation or abandonment of the position heretofore maintained by each of them.

[TRADUCTION]

L'application de la présente Convention dans des territoires sur lesquels deux ou plusieurs Etats, qu'ils soient ou non parties à ladite Convention, ont des prétentions adverses à exercer la souveraineté, ne pourra être interprétée comme signifiant que chacun d'eux modifie la position qu'il a maintenue jusqu'à présent, y renonce ou l'abandonne.

CANADA (a)

"In acceding to the Vienna Convention on the Law of Treaties, the government of Canada declares its understanding that nothing in article 66 of the Convention is intended to exclude the jurisdiction of the International Court of Justice where such jurisdiction exists under the provisions of any treaty in force binding the parties with regard to the settlement of disputes. In relation to states parties to the Vienna Convention which accept as compulsory the jurisdiction of the International Court of Jus-

CANADA (a)

«En adhérant à la Convention de Vienne sur le droit des traités, le Gouvernement du Canada déclare reconnaître qu'il n'y a rien dans l'article 66 de la Convention qui tende à exclure la compétence de la Cour internationale de Justice lorsque cette compétence est établie en vertu des dispositions d'un traité en vigueur dont les parties sont liées relativement au règlement des différends. En ce qui concerne les Etats parties à la Convention de Vienne qui acceptent que la compétence de la Cour internationale

tice, the government of Canada declares that it does not regard the provisions of article 66 of the Vienna Convention as providing 'some other method of peaceful settlement' within the meaning of paragraph 2 (*a*) of the declaration of the government of Canada accepting as compulsory the jurisdiction of the International Court of Justice which was deposited with the Secretary-General of the United Nations on April 7, 1970."[1]

de Justice soit obligatoire, le Gouvernement du Canada déclare qu'il ne considère pas que les dispositions de l'article 66 de la Convention de Vienne proposent «un autre moyen de règlement pacifique», selon la teneur de l'alinéa *a* du paragraphe 2 de la déclaration que le Gouvernement du Canada a remise au Secrétaire général de l'Organisation des Nations Unies le 7 avril 1970, par laquelle il acceptait que la compétence de la Cour internationale de Justice soit obligatoire[1].»

DENMARK

[TRANSLATION — TRADUCTION]

As between itself and any State which formulates, wholly or in part, a reservation relating to the provisions of article 66 of the Convention concerning the compulsory settlement of certain disputes, Denmark will not consider itself bound by those provisions of part V of the Convention, according to which the procedures for settlement set forth in article 66 are not to apply in the event of reservations formulated by other States.

DANEMARK

«Vis-à-vis de pays formulant entièrement ou partiellement des réserves en ce qui concerne les dispositions de l'article 66 de la Convention portant sur le règlement obligatoire de certains différends, le Danemark ne se considère pas lié par les dispositions de la partie V de la Convention, selon lesquelles les procédures de règlement indiquées à l'article 66 ne seront pas appliquées par suite de réserves formulées par d'autres pays.»

FINLAND

"Finland declares its understanding that nothing in paragraph 2 of article 7 of the Convention is intended to modify any provisions of internal law in force in any Contracting State concerning competence to conclude treaties. Under the Constitution of Finland the competence to conclude treaties is given to the President of the Republic, who also decides on the issuance of full powers to the Head of Government and the Minister for Foreign Affairs.

FINLANDE

[TRADUCTION — TRANSLATION]

La Finlande déclare qu'elle considère qu'aucune des dispositions du paragraphe 2 de l'article 7 de la Convention ne vise à modifier les dispositions de droit interne concernant la compétence pour conclure des traités en vigueur dans un Etat contractant. En vertu de la Constitution finlandaise, c'est le Président de la République qui est habilité à conclure des traités et c'est également lui qui décide de donner pleins pouvoirs au Chef du Gouvernement et au Ministre des affaires étrangères.

[1] United Nations, *Treaty Series*, vol. 724, p. 63.

[1] Nations Unies, *Recueil des Traités*, vol. 724, p. 63.

"Finland also declares that as to its relation with any State which has made or makes a reservation to the effect that this State will not be bound by some or all of the provisions of article 66, Finland will consider itself bound neither by those procedural provisions nor by the substantive provisions of part V of the Convention to which the procedures provided for in article 66 do not apply as a result of the said reservation."

La Finlande déclare également qu'en ce qui concerne ses relations avec tout Etat qui a fait ou fait une réserve telle que cet Etat n'est pas lié par quelques-unes des dispositions de l'article 66 ou par toutes ces dispositions la Finlande ne se considérera liée ni par ces dispositions de procédure ni par les dispositions de fond de la partie V de la Convention auxquelles les procédures prévues à l'article 66 ne s'appliquent pas par suite de ladite réserve.

KUWAIT (a)

KOWEÏT (a)

[ARABIC TEXT — TEXTE ARABE]

مع التحفظ الخاص بأن الارتباط بهذه الاتفاقية لا يحوى بأية حال معنى الاعتراف بأسرائيل ولا يؤدى الى الدخول معها فى معاملات مما تنظمة هذه الاتفاقية ،كما تعهد بمراعاتها والامر بمراعاتها دون أنتهاك حرمتها .

[TRANSLATION[1] — TRADUCTION[2]]

"The participation of Kuwait in this Convention does not mean in any way recognition of Israel by the Government of the State of Kuwait and that, furthermore, no treaty relations will arise between the State of Kuwait and Israel."

[TRADUCTION — TRANSLATION]

La participation du Koweït à ladite Convention ne signifie en aucune façon que le Gouvernement de l'Etat du Koweït reconnaisse Israël, et qu'en outre aucune relation conventionnelle ne sera établie entre l'Etat du Koweït et Israël.

MOROCCO

MAROC

[For the text of the declaration, see p. 499 of this volume.]

[Pour le texte de la déclaration, voir p. 499 du présent volume.]

SYRIAN ARAB REPUBLIC (a)

RÉPUBLIQUE ARABE SYRIENNE (a)

[ARABIC TEXT — TEXTE ARABE]

٢ — ان قبول الجمهورية العربية السورية هذه الاتفاقية وابرام حكومتها لها لا يحوى بأية حال معنى الاعتراف باسرائيل ولا يؤدى الى دخولها معها في معاملات مما تنظمه أحكامها .

[1] Translation supplied by the Government of Kuwait.
[2] Traduction fournie par le Gouvernement du Koweït.

ب — ان الجمهورية العربية السورية تعتبر أن المادة الواحدة والثمانين من هذه الاتفاقية لا تتفق وأهداف الاتفاقية وغايتها اذ أنها لا تمكن جميع الدول بدون تفرقة أو تمييز من أن تصبح اطرافا فيها .

ج — ان حكومة الجمهورية العربية السورية لا تقبل بحال من الاحوال عدم سريان مبدأ التغيير الجوهري للظروف على المعاهدات التي تنشيء حدودا في الفقرة ٢ (أ) من المادة الثانية والستين لان ذلك يعتبر خرقا واضحا لواحدة من القواعد الآمرة في القواعد العامة للقانون الدولي والقاضية بحق الشعوب في تقرير مصيرها .

د — ان حكومة الجمهورية العربية السورية تفهم حكم المادة الثانية والخمسين على النحو التالي :

" ان عبارة التهديد بالقوة واستخدامها الواردة في هذه المادة تنصرف ايضا الى ممارسة الضغوط الاقتصادية والسياسية والعسكرية والنفسية وسائر انواع الضغوط الاخرى التي من شأنها حمل الدولة على الدخول في معاهدة ضد رغبتها أو مصلحتها .

هـ — ان انضمام الجمهورية العربية السورية الى هذه الاتفاقية وابرام حكومتها لها لا يسري على الملحق بهذه الاتفاقية المتعلق بالتوفيق الالزامي .

[TRANSLATION — TRADUCTION]

A. Acceptance of this Convention by the Syrian Arab Republic and ratification of it by its Government shall in no way signify recognition of Israel and cannot have as a result the establishment with the latter of any contact governed by the provisions of this Convention.

B. The Syrian Arab Republic considers that article 81 is not in conformity with the aims and purposes of the Convention in that it does not allow all States, without distinction or discrimination, to become parties to it.

C. The Government of the Syrian Arab Republic does not in any case accept the non-applicability of the principle of a fundamental change of circumstances with regard to treaties establishing boundaries, referred to in article 62, paragraph 2 (*a*), inasmuch as it regards this as a flagrant violation of an obligatory norm which forms part of general in-

[TRADUCTION[1] — TRANSLATION[2]]

«A) L'acceptation de cette Convention par la République arabe syrienne et sa ratification par son Gouvernement ne peuvent comporter en aucune façon le sens d'une reconnaissance d'Israël et ne peuvent aboutir à entretenir avec lui aucun contact réglé par les dispositions de la Convention.

«B) La République arabe syrienne considère que l'article quatre-vingt-un de cette Convention ne s'accorde pas avec ses buts et ses desseins car il ne permet pas à tous les Etats sans discrimination ou distinction d'en devenir parties.

«C) Le Gouvernement de la République arabe syrienne n'accepte en aucun cas la non-application du principe du changement fondamental de circonstances sur les traités établissant des frontières au paragraphe 2, alinéa *a*, de l'article soixante-deux, car cela est considéré comme une violation flagrante de l'une des règles obligatoires parmi les règles

[1] Traduction fournie par le Gouvernement de la République arabe syrienne.

[2] Translation supplied by the Government of the Syrian Arab Republic.

ternational law and which recognizes the right of peoples to self-determination.

D. The Government of the Syrian Arab Republic interprets the provisions in article 52 as follows:

> The expression "the threat or use of force" used in this article extends also to the employment of economic, political, military and psychological coercion and to all types of coercion constraining a State to conclude a treaty against its wishes or its interests.

E. The accession of the Syrian Arab Republic to this Convention and the ratification of it by its Government shall not apply to the Annex to the Convention, which concerns obligatory conciliation.

générales du Code international et qui prévoit le droit des peuples à l'autodétermination.

«D) Le Gouvernement de la République arabe syrienne comprend la disposition de l'article cinquante-deux, comme suit :

> «Le terme de la menace ou l'emploi de la force prévu par cet article s'applique également à l'exercice des contraintes économiques, politiques, militaires et psychologiques ainsi que tous les genres de contraintes qui entraînent l'obligation d'un Etat à conclure un traité contre son désir ou son intérêt.»

«E) L'adhésion de la République arabe syrienne à cette Convention et sa ratification par son Gouvernement ne s'appliquent pas à l'Annexe à la Convention relative à la conciliation obligatoire.»

TUNISIA (a)

[TRANSLATION — TRADUCTION]

The dispute referred to in article 66 (*a*) requires the consent of all parties thereto in order to be submitted to the International Court of Justice for a decision.

TUNISIE (a)

«Le différend prévu au paragraphe *a* de l'article 66 nécessite l'accord de toutes les parties à ce différend pour être soumis à la décision de la Cour internationale de Justice.»

UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

It is [the United Kingdom's] understanding that nothing in article 66 of the Convention is intended to oust the jurisdiction of the International Court of Justice where such jurisdiction exists under any provisions in force binding the parties with regard to the settlement of disputes. In particular, and in relation to States parties to the Vienna Convention which accept as compulsory the jurisdiction of the International Court, the

ROYAUME-UNI DE GRANDE-BRETAGNE ET D'IRLANDE DU NORD

[TRADUCTION — TRANSLATION]

Le Royaume-Uni considère qu'aucune disposition de l'article 66 de la Convention ne vise à écarter la juridiction de la Cour internationale de Justice lorsque cette juridiction découle de clauses en vigueur entre les parties, concernant le règlement des différends et ayant force obligatoire à leur égard. Notamment, au regard des Etats parties à la Convention de Vienne qui acceptent comme obligatoire la juridiction de la Cour internatio-

United Kingdom will not regard the provisions of sub-paragraph (*b*) of article 66 of the Vienna Convention on the Law of Treaties as providing 'some other method of peaceful settlement' within the meaning of sub-paragraph (i) (*a*) of the Declaration of the Government of the United Kingdom which was deposited with the Secretary-General of the United Nations on the 1st of January 1969."

UNITED REPUBLIC OF TANZANIA (a)

"Article 66 of the Convention shall not be applied to the United Republic of Tanzania by any State which enters a reservation on any provision of part V or the whole of that part of the Convention."

OBJECTION[1] to the declaration made by the Government of Finland upon ratification[2]

UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

Received on:
7 December 1977

"The Government of the United Kingdom of Great Britain and Northern Ireland note that the instrument of ratification of the Government of Finland, which was deposited with the Secretary-General on 19 August 1977, contains a declaration relating to paragraph 2 of article 7 of the Convention. The Government of the United Kingdom wish to inform the Secretary-General that they do not regard that declaration as in any way affecting the interpretation or application of article 7."

[1] Unless otherwise indicated, the texts of the objections were received at the time of ratification or accession.
[2] See p. 503 of this volume.

nale de Justice, le Royaume-Uni ne considérera pas les dispositions de l'alinéa *b* de l'article 66 de la Convention de Vienne sur le droit des traités comme fournissant «un autre moyen de règlement pacifique», au sens de l'alinéa i, *a*, de la Déclaration que le Gouvernement du Royaume-Uni a déposée auprès du Secrétaire général de l'Organisation des Nations Unies le 1er janvier 1969.

RÉPUBLIQUE-UNIE DE TANZANIE (a)

[TRADUCTION — TRANSLATION]

Aucun Etat formulant des réserves à propos d'une quelconque disposition de la partie V de la Convention, ou de l'ensemble de cette partie, ne pourra invoquer l'article 66 de la Convention vis-à-vis de la République-Unie de Tanzanie.

OBJECTION[1] à la déclaration faite par le Gouvernement finlandais lors de la ratification[2]

ROYAUME-UNI DE GRANDE BRETAGNE ET D'IRLANDE DU NORD

Reçue le :
7 décembre 1977

[TRADUCTION — TRANSLATION]

Le Gouvernement du Royaume-Uni de Grande-Bretagne et d'Irlande du Nord prend note que l'instrument de ratification du Gouvernement finlandais, déposé auprès du Secrétaire général le 19 août 1977, contient une déclaration relative au paragraphe 2 de l'article 7 de la Convention. Le Gouvernement du Royaume-Uni informe le Secrétaire général qu'il considère que cette déclaration ne modifie aucunement l'interprétation ou l'application de l'article 7.

[1] Sauf indication contraire, la date de réception est celle de la ratification ou de l'adhésion.
[2] Voir p. 503 du présent volume.

OBJECTION to the reservation made by the Government of Guatemala upon signature[1]

UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

"With reference to a reservation in relation to the territory of British Honduras made by Guatemala on signing the Convention, the United Kingdom does not accept that Guatemala has any rights or any valid claim with respect to that territory;

"The United Kingdom fully reserves its position in other respects with regard to the declarations made by various States on signature, to some of which the United Kingdom would object, if they were to be confirmed on ratification."

OBJECTIONS to the declaration made by the Government of the Syrian Arab Republic upon accession[2]

CANADA

Received on:
22 October 1971

". . . Canada does not consider itself in treaty relations with the Syrian Arab Republic in respect of those provisions of the Vienna Convention on the Law of Treaties to which the compulsory conciliation procedures set out in the annex to that Convention are applicable."

OBJECTION à la réserve faite par le Gouvernement guatémaltèque lors de la signature[1]

ROYAUME-UNI DE GRANDE-BRETAGNE ET D'IRLANDE DU NORD

[TRADUCTION — TRANSLATION]

S'agissant de la réserve relative au territoire du Honduras britannique qui a été formulée par le Guatemala lors de la signature de la Convention, le Royaume-Uni ne reconnaît au Guatemala aucun droit ni titre légitime de réclamation en ce qui concerne ce territoire.

Le Royaume-Uni réserve pleinement sa position sur d'autres points vis-à-vis des déclarations qui ont été faites par divers Etats lors de la signature de la Convention; si certaines d'entre elles venaient à être confirmées lors de la ratification, le Royaume-Uni formulerait des objections à leur encontre.

OBJECTIONS à la réserve faite par le Gouvernement de la République arabe syrienne lors de l'adhésion[2]

CANADA

Reçue le :
22 octobre 1971

«Le Canada ne se considère pas comme lié par traité avec la République arabe syrienne à l'égard des dispositions de la Convention de Vienne sur le droit des traités auxquelles s'appliquent les procédures de conciliation obligatoire énoncées à l'annexe de ladite Convention.»

[1] See p. 498 of this volume.
[2] See p. 504 of this volume.

[1] Voir p. 498 du présent volume.
[2] Voir p. 504 du présent volume.

NEW ZEALAND

Received on:
14 October 1971

". . . The New Zealand Government objects to the reservation entered by the Government of Syria to the obligatory conciliation procedures contained in the annex to the Vienna Convention on the Law of Treaties and does not accept the entry into force of the Convention as between New Zealand and Syria."

UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

"The United Kingdom does not accept that the interpretation of article 52 put forward by the Government of Syria correctly reflects the conclusions reached at the Conference of Vienna on the subject of coercion; the Conference dealt with this matter by adopting a Declaration on this subject which forms part of the Final Act.

"The United Kingdom objects to the reservation entered by the Government of Syria in respect of the annex to the Convention and does not accept the entry into force of the Convention as between the United Kingdom and Syria".

OBJECTION to the reservations made by the Government of the Syrian Arab Republic and by the Government of Tunisia, respectively, upon accession[1]

SWEDEN

Received on:

4 February 1975

"Article 66 of the Convention contains certain provisions regarding procedures

[1] See pp. 504 and 506 of this volume.

NOUVELLE-ZÉLANDE

Reçue le :
14 octobre 1971

[TRADUCTION — TRANSLATION]

Le Gouvernement néo-zélandais objecte à la réserve formulée par le Gouvernement syrien relative aux procédures de conciliation obligatoire prévues dans l'annexe à la Convention de Vienne sur le droit des traités et n'accepte pas l'entrée en vigueur de la Convention entre la Nouvelle-Zélande et la Syrie.

ROYAUME-UNI DE GRANDE-BRETAGNE ET D'IRLANDE DU NORD

[TRADUCTION — TRANSLATION]

Le Royaume-Uni ne considère pas que l'interprétation de l'article 52 qui a été avancée par le Gouvernement syrien reflète avec exactitude les conclusions auxquelles la Conférence de Vienne est parvenue au sujet de la contrainte; la Conférence a réglé cette question en adoptant à son sujet une déclaration qui fait partie de l'Acte final.

Le Royaume-Uni formule une objection contre la réserve faite par le Gouvernement syrien au sujet de l'annexe à la Convention et ne reconnaît pas l'entrée en vigueur de cette dernière entre le Royaume-Uni et la Syrie.

OBJECTION aux réserves faites par le Gouvernement de la République arabe syrienne et par le Gouvernement de la Tunisie, respectivement, lors de l'adhésion[1]

SUÈDE

Reçue le :

4 février 1975

[TRADUCTION — TRANSLATION]

L'article 66 de la Convention contient certaines dispositions concernant les

[1] Voir p. 504 et p. 506 du présent volume.

for judicial settlement, arbitration and conciliation. According to these provisions a dispute concerning the application or the interpretation of article 53 or 64, which deal with the so-called *jus cogens*, may be submitted to the International Court of Justice. If the dispute concerns the application or the interpretation of any of the other articles in Part V of the Convention, the conciliation procedure specified in the Annex to the Convention may be set in motion.

"The Swedish Government considers that these provisions regarding the settlement of disputes are an important part of the Convention and that they cannot be separated from the substantive rules with which they are connected. Consequently, the Swedish Government considers it necessary to raise objections to any reservation which is made by another State and whose aim is to exclude the application, wholly or in part, of the provisions regarding the settlement of disputes. While not objecting to the entry into force of the Convention between Sweden and such a State, the Swedish Government considers that their treaty relations will not include either the procedural provision in respect of which a reservation has been made or the substantive provisions to which that procedural provision relates.

"For the reasons set out above, the Swedish Government objects to the reservation of the Syrian Arab Republic, according to which its accession to the Convention shall not include the Annex, and to the reservation of Tunisia, according to which the dispute referred to in article 66 (*a*) requires the consent of all parties thereto in order to be submitted to the International Court of Justice for a decision. In view of these reservations, the Swedish Government considers, firstly, that the treaty relations between Sweden and the Syrian Arab Republic will not include those provisions of Part V of the Convention to

procédures du règlement judiciaire, d'arbitrage et de conciliation. Aux termes de ces dispositions, un différend concernant l'application ou l'interprétation des articles 53 ou 64, qui traitent de ce que l'on appelle le *jus cogens*, peut être soumis à la décision de la Cour internationale de Justice. Si le différend concerne l'application ou l'interprétation de l'un quelconque des autres articles de la partie V de la Convention, la procédure de conciliation indiquée à l'annexe à la Convention peut être mise en œuvre.

Le Gouvernement suédois estime que ces dispositions relatives au règlement des différends constituent une partie importante de la Convention et qu'elles ne peuvent être dissociées des règles de fond auxquelles elles sont liées. Par conséquent, le Gouvernement suédois objecte à toutes les réserves qu'un autre Etat pourrait faire dans le but d'éviter, totalement ou partiellement, l'application des dispositions relatives au règlement des différends. Bien qu'il ne s'oppose pas à l'entrée en vigueur de la Convention entre la Suède et un tel Etat, le Gouvernement suédois estime que ni les dispositions de procédure faisant l'objet de réserves ni les dispositions de fond auxquelles ces dispositions de procédure se rapportent ne seront comprises dans leurs relations conventionnelles.

Pour les raisons évoquées ci-dessus, le Gouvernement suédois objecte à la réserve de la République arabe syrienne selon laquelle son adhésion à la Convention n'entraîne pas son adhésion à l'annexe à la Convention, et à la réserve de la Tunisie selon laquelle le différend dont il est question à l'article 66, *a*, ne peut être soumis à la décision de la Cour internationale de Justice qu'avec l'assentiment de toutes les parties à ce différend. Etant donné ces réserves, le Gouvernement suédois estime, premièrement, que les dispositions de la partie V de la Convention auxquelles se rapporte la procédure de conciliation indiquée à

which the conciliation procedure in the Annex applies and, secondly, that the treaty relations between Sweden and Tunisia will not include articles 53 and 64 of the Convention.

"The Swedish Government has also taken note of the declaration of the Syrian Arab Republic, according to which it interprets the expression 'the threat or use of force' as used in article 52 of the Convention so as to extend also to the employment of economic, political, military and psychological coercion and to all types of coercion constraining a State to conclude a treaty against its wishes or its interests. On this point, the Swedish Government observes that since article 52 refers to threat or use of force in violation of the principles of international law embodied in the Charter of the United Nations, it should be interpreted in the light of the practice which has developed or will develop on the basis of the Charter."

l'annexe ne seront pas comprises dans les relations conventionnelles entre la Suède et la République arabe syrienne et, deuxièmement, que les relations conventionnelles entre la Suède et la Tunisie n'engloberont pas les articles 53 et 64 de la Convention.

Le Gouvernement suédois a également pris note de la déclaration faite par la République arabe syrienne selon laquelle celle-ci interprète l'expression «la menace ou l'emploi de la force» utilisée à l'article 52 de la Convention comme s'appliquant également à l'emploi de contraintes économiques, politiques, militaires et psychologiques et les pressions de toute nature exercées en vue de contraindre un Etat à conclure un traité contre son gré ou contre ses intérêts. A ce propos, le Gouvernement suédois fait remarquer qu'étant donné que l'article 52 traite de la menace ou de l'emploi de la force en violation des principes du droit international incorporés dans la Charte des Nations Unies, il conviendrait de l'interpréter en tenant compte de la pratique qui s'est instaurée ou qui s'instaurera en ce qui concerne l'application des dispositions de la Charte.

OBJECTIONS to the reservation made by the Government of Tunisia upon accession[1]

UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

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". . . The United Kingdom objects to the reservation entered by the Government of Tunisia in respect of article 66 (*a*) of the Convention and does not accept the entry into force of the Convention as between the United Kingdom and Tunisia."

[1] See p. 506 of this volume.

OBJECTIONS à la réserve faite par le Gouvernement tunisien lors de l'adhésion[1]

ROYAUME-UNI DE GRANDE-BRETAGNE ET D'IRLANDE DU NORD

Reçue le :

22 juin 1972

[TRADUCTION — TRANSLATION]

Le Royaume-Uni objecte à la réserve formulée par le Gouvernement tunisien au sujet de l'article 66, *a*, de la Convention et ne reconnaît pas l'entrée en vigueur de cette dernière entre le Royaume-Uni et la Tunisie.

[1] Voir p. 506 du présent volume.

NEW ZEALAND

Received on:

10 August 1972

". . . The New Zealand Government objects to the reservation entered by the Government of Tunisia in respect of article 66 (*a*) of the Convention and does not consider New Zealand to be in treaty relations with Tunisia in respect of those provisions of the Convention to which the dispute settlement procedure provided for in article 66 (*a*) is applicable."

NOUVELLE-ZÉLANDE

Reçue le :

10 août 1972

[TRADUCTION — TRANSLATION]

Le Gouvernement néo-zélandais fait objection à la réserve émise par le Gouvernement tunisien à propos de l'article 66, *a*, de la Convention, et il considère que la Nouvelle-Zélande n'est pas liée par traité avec la Tunisie en ce qui concerne les dispositions de la Convention auxquelles la procédure de règlement des différends prévues à l'article 66, *a*, est applicable.

REPORTS

INDUCED SEISMICITY

High-rate injection is associated with the increase in U.S. mid-continent seismicity

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An unprecedented increase in earthquakes in the U.S. mid-continent began in 2009. Many of these earthquakes have been documented as induced by wastewater injection. We examine the relationship between wastewater injection and U.S. mid-continent seismicity using a newly assembled injection well database for the central and eastern United States. We find that the entire increase in earthquake rate is associated with fluid injection wells. High-rate injection wells (>300,000 barrels per month) are much more likely to be associated with earthquakes than lower-rate wells. At the scale of our study, a well's cumulative injected volume, monthly wellhead pressure, depth, and proximity to crystalline basement do not strongly correlate with earthquake association. Managing injection rates may be a useful tool to minimize the likelihood of induced earthquakes.

The injection of fluids into the subsurface has been known to induce earthquakes since the mid-1960s (*1*–*3*). However, few additional cases of earthquakes induced by wastewater injection have been documented until 2009 (*4*). The hazard from these earthquakes was considered small because they were infrequent and not expected to be large (largest observed prior to 2011 was the M 4.9 Rocky Mountain Arsenal earthquake in 1967) (*4*–*6*). The central and eastern United States (CEUS) has seen an unprecedented increase in earthquake rate since 2009, and many of these earthquakes are believed to be induced (*7*). Along with the increased rate, several damaging earthquakes have occurred such as the 2011 magnitude (M) 5.6 Prague, Oklahoma, earthquake (*8*, *9*), the 2011 M 5.3 Trinidad, Colorado, earthquake (*10*), the 2012 M 4.8 Timpson, Texas, earthquake (*11*), and the 2011 M 4.7 Guy, Arkansas, earthquake (*12*). The increased earthquake rate and occurrence of multiple damaging earthquakes has prompted the scientific community to refocus efforts to understand the hazard posed by injection-induced earthquakes (*13*).

The sudden appearance of several large, potentially induced earthquakes led to many site-specific case studies (*4*). These case studies examined the operation of injection wells in close proximity to the earthquakes, showing a link between the timing and location of injection and seismicity (*12*, *14*–*18*). Though useful to understand the individual systems in which these earthquakes occurred, broader-scale studies are needed to understand the phenomenon as a whole. One previous study examined earthquakes in Texas's Barnett Shale region and found that earthquakes are commonly located near wells injecting more than 150,000 barrels per month (*19*). However, to fully understand the possibility of induced seismicity associated with a given injection well, we must analyze a range of geologic, hydrogeologic, and operational differences between injection wells that are potentially associated with earthquakes and those that are not.

We examined the location and timing of earthquakes and their relationship to the location and operation of injection wells across the CEUS (Fig. 1). We compiled a database from publicly available sources that documents the location and operational parameters of underground injection control class II injection wells in the CEUS (Fig. 1 and table S1). Class II injection wells inject fluids associated with oil and gas production and are distinct from hydraulically fractured production wells (*20*). The database contained 187,570 wells as of December 2014, with 56% actively injecting fluid (Fig. 1) and the remaining 44% being inactive or abandoned. About 75% of the active class II injection wells operated for the purposes of enhanced oil recovery (EOR), whereas nearly all of the remaining wells were designated as salt water disposal (SWD) wells (fig. S1). EOR wells inject fluid into depleted oil reservoirs to increase oil production. SWD wells inject to dispose of waste fluids produced by oil and gas production, which would otherwise be hazardous to surface waters or underground sources of drinking water. Injection wells are geographically clustered in the basins and regions of major oil and gas operations. Texas, Oklahoma, Kansas, and Wyoming contain ~85% of all class II injection wells in the CEUS. The spatial density of active SWD wells is highest (≥5 wells per 5 km^2) in the Forth Worth Basin of north-central Texas and the Mississippi Lime Play extending from north-central Oklahoma northward into central Kansas. The spatial density of active EOR wells is highest (≥5 wells per 5 km^2) in the Permian Basin of West Texas, the Fort Worth Basin, south-central Oklahoma, and southeastern Kansas (fig. S1).

We obtained earthquake location and magnitude data from the Advanced National Seismic System's comprehensive earthquake catalog (ANSS ComCat) (*21*). During the study period (1973 to 2014), we identified 7175 $M \geq 0.0$ events in the catalog in the CEUS region (Fig. 2). Although the catalog is not complete down to M 0.0 during the study period, we treated all earthquakes as potentially induced events to capture the most comprehensive data set of associated earthquakes and injection wells. We used a magnitude of completeness of 3.0 when comparing associated versus nonassociated earthquakes through time (*7*).

We used spatial and temporal filtering methods to discriminate injection wells that may be associated with earthquakes from those that are probably not. We considered any earthquake within 15 km of an active injection well to be associated with that well. This distance of association is based upon the sum of a 5-km radius within which earthquakes are traditionally considered as potentially induced (*22*) and a 10-km estimate of the spatial uncertainty in earthquake epicenter location in the CEUS (*23*). We designed the temporal filter to include only injection wells active at the time of the spatially associated earthquake. Both filters could be considered conservative, because induced seismicity has been found tens of kilometers from injection wells (*24*) and also after a well is shut-in (*25*) owing to the injection prior to the well becoming inactive (*4*, *5*). To analyze the sensitivity of our results to these filtering parameters, we also tested our analysis using spatial association distances of 5 and 10 km. This first-order analysis attempts to understand which basic well properties affect the likelihood of earthquake association.

We find 18,757 injection wells (~10% of all wells) associated with earthquakes in the CEUS after filtering, mostly in the states of Oklahoma and Texas (Fig. 1). The number of associated injection wells has tripled since the year 2000 (fig. S2). The spatiotemporal filter identifies every case of induced seismicity from class II injection wells documented in the literature for the CEUS region (table S2). We identify far more injection wells that are potentially related to earthquakes than those indicated by published cases. Of the wells that are associated with earthquakes, 66% are EOR wells. However, active SWD wells are more than 1.5 times as likely as active EOR wells to be associated with an earthquake, which accounts for their respective well totals (Fig. 1). The finding that SWD wells are preferentially associated with earthquakes likely resides with difference in well operation. SWD injection causes a net-positive reservoir pressure change, whereas EOR injection and extraction

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wells are typically operated in tandem with injection rates managed carefully to balance reservoir pressures (*7*).

Over the past four decades, more than 60% of all CEUS seismicity (*M* 3.0+) is associated with injection wells using our filtering criteria (Figs. 2 and 3). Varying the spatial distance of association by several kilometers only changes this percentage by ±5% (fig. S3). Before the year 2000, an average of ~20% of all CEUS seismicity was associated with injection wells. The yearly percentage of associated earthquakes has risen sharply to ~87% from 2011 to 2014 (Fig. 3 and fig. S4). The percentage increase of associated earthquakes, combined with the rising CEUS earthquake rate, implies that recent seismicity in the CEUS is preferentially occurring near injection wells. The number of nonassociated earthquakes during the same period has also remained stable (Fig. 3). This increase in associated earthquake rate does not correspond to an increase in the rate of wells completed; the well completion rate has remained constant over this period (fig. S5) (*26*). A portion of the increase in associated earthquakes may be due to increasing spatial coverage of wells, but we suggest that this effect is minimal, considering that the relative increase in spatial coverage was much more rapid between 1960 and 1980 than in recent years (fig. S5). Wells in central and north-central Oklahoma are the main contributors to the dramatic increase in associated seismicity. New production methods in these regions are generating large volumes of produced water, which are injected at high rates (fig. S6, A and B) (*27*). Regions such as west Texas, southern Colorado, central Arkansas, and southern Illinois also show concentrations of seismicity associated with injection wells (Fig. 2). However, several regions with large numbers of injection wells appear to be aseismic during the study period, including the Williston Basin of North Dakota (*28*), the Michigan Basin, and extensive areas of the Texas and Louisiana Gulf Coast (Figs. 1 and 2).

Several operational parameters are hypothesized to influence the likelihood of an induced seismic event: injection rate (*19*, *24*), cumulative injected volume (*29*, *30*), wellhead injection pressure (*31*), and injection in proximity to crystalline basement (*18*, *32*). Four states—Oklahoma, Arkansas, Colorado, and New Mexico—with both natural and induced earthquakes all have more than 15 years of injection data that include readily accessible information on monthly injection rate and pressure for a large proportion of operational wells. Using these data, we explore injection operational parameter control on the likelihood that SWD and EOR wells will be associated with earthquakes.

The maximum monthly injection rate of wells across these four states varies by several orders of magnitude, ranging from 100 barrels (~15.9 m^3) per month (bbl/month) up to 2 million bbl/month (~318,000 m^3) (Fig. 4A) (*33*). The average SWD well operates at a mean monthly rate of ~13,000 bbl/month. For each histogram bin in Fig. 4, A and B, we calculate the percentage of wells associated with earthquakes. The likelihood that an SWD well is associated with earthquakes increases as the maximum injection rate increases (Fig. 4C). To discern whether the association is random, we estimated upper (95%) and lower (5%) confidence bounds using a bootstrapped resampling method with 10,000 resamples (Fig. 4C) (*34*, *35*). Wells operating at maximum injection rates greater than 300,000 bbl/month fall outside the bootstrap resampling confidence bounds, suggesting a greater-than-expected likelihood of association with an earthquake at a statistical significance near 99%. This is contrasted with wells operating at maximum injection rates less than 100,000 bbl/month, which mostly fall within the bounds of random association. We confirmed this result using spatial distances of association of 5 and 10 km (fig. S7), as well as restricting our well associations to earthquakes greater than *M* 3.0 (fig. S8). Of the 413 wells operating at injection rates greater than 300,000 bbl/month, 253 (61%) are spatiotemporally associated compared with only 40% of wells operating at injection rates less than 10,000 bbl/month. Additionally, 34 (76%) of the 45 highest-rate SWD wells (injecting more than a million barrels per month) are associated with an earthquake. When SWD operations are examined state by state, the overall percentage associated varies, but the trend of increased earthquake association at higher rates is generally preserved (fig. S9A). Fewer data are available for EOR wells, but we do not observe a clear trend of increasing earthquake association with increasing injection rate for EOR wells (fig. S10A). Without considering geologic or hydrogeologic setting, the highest-rate SWD wells are nearly twice as likely to be near an earthquake as are low-rate SWD wells.

We next examine whether cumulative injected volume affects the likelihood of well association with earthquakes. For the four states examined during the period from 1973 to 2014, cumulative injected volume ranged from 1000 bbl to nearly 100 million bbl (Fig. 4B). Many large cumulative volume wells inject at moderate rates for decades, providing a contrasting data set from maximum injection rate. We do not observe a strong trend of increasing SWD well association as a function of increasing cumulative injected volume (Fig. 4D). The difference between the association rate of wells that have injected more than 1,000,000 bbl cumulatively (45%) and those which

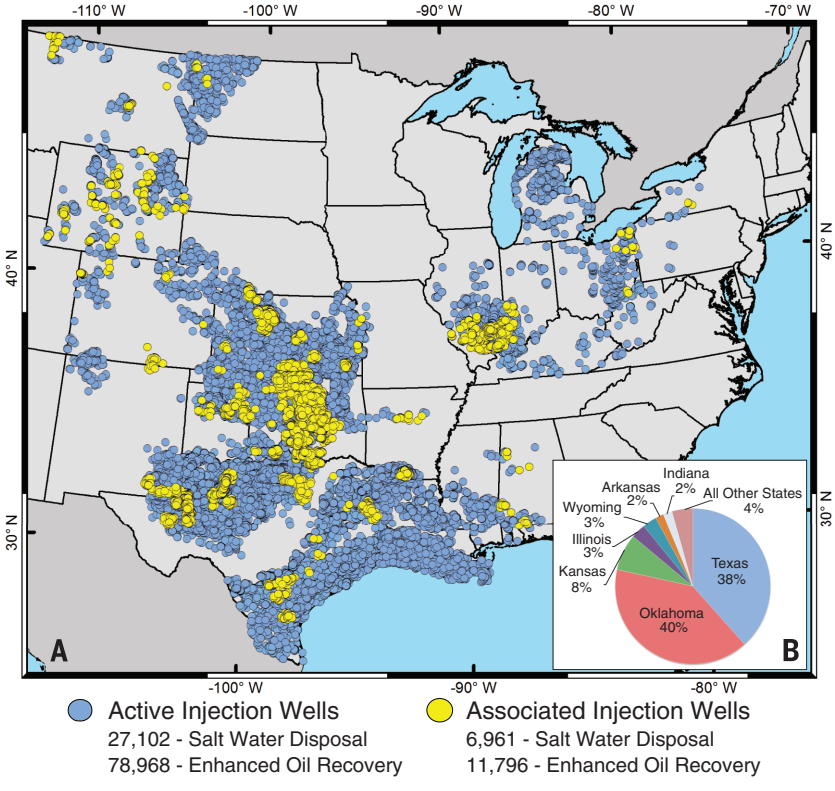


Fig. 1. Active and associated class II injection wells in the CEUS. (**A**) Map showing the location of active class II injection wells in the CEUS. Active injection wells from the database are shown as blue circles. Spatiotemporally associated injection wells, defined as those within a 15-km radius and active at the time of an earthquake, are shown as yellow circles. The CEUS region comprises all states intersected by 109°W longitude and eastward. The total number of wells, including inactive or abandoned wells in the CEUS, is 188,570. Of the 18,757 associated injection wells, >77% are currently active. (**B**) The inset pie diagram shows spatiotemporally associated injection wells by state. Only 8% of all injection wells are located in Oklahoma, but 40% of the associated injection wells in the CEUS are located in Oklahoma.

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have injected less than 10,000 bbl cumulatively (38%) is not statistically significant, as determined by a bootstrap resampling method (*35*). The percentage of wells associated with earthquakes at high cumulative injected volumes can be mostly explained by random variation given the total number of associated and nonassociated wells. EOR wells exhibit a trend of earthquake association similar to that of SWD wells as a function of cumulative injected volume (fig. S10B). If we instead calculate cumulative injected volume not for individual wells, but for all wells within 15 km of an associated earthquake, we observe a log-normal distribution of volumes without a clear threshold of increased earthquake association (fig. S11). We do not observe cumulative injected volume as strongly affecting the likelihood of an injection well's association with an earthquake.

The majority of class II injection wells operate at monthly wellhead injection pressures less than 500 pounds per square inch (psi). Reported wellhead pressures for both SWD and EOR wells ranged from 0 to 3000 psi (fig. S12, A and B). In the same four states studied, the proportion of SWD and EOR wells associated with earthquakes show no strong correlation toward increased monthly wellhead pressures (figs. S12 and S13). However, reported monthly wellhead pressure may not always be reliable because many wells report constant wellhead pressures despite changing injection rates. Wellhead injection pressure data may not reflect the pore-pressure conditions in the injection formation due to friction in the wellbore and other factors. In addition, wells reporting zero wellhead pressure still create bottomhole pressure from the hydrostatic fluid column in the well that could be large enough induce an earthquake. There are several hundred wells with zero wellhead pressures that are associated with earthquakes (fig. S12, A and B). This is consistent with field observations of earthquakes induced by wells with zero wellhead pressure (*10*, *36*). We do not consider the reported maximum wellhead pressure to be a controlling factor on injection well and earthquake association. This finding, together with the indication that SWD wells are preferentially associated with earthquakes, underscores the need to collect reservoir pressure data. Ideally, preinjection reservoir pore pressure and bottomhole formation pressure measurements during injection would prove more useful in determining whether a link exists between injection pressure and earthquakes.

Injection depth and proximity to crystalline basement have been hypothesized to affect the likelihood that wells are associated with earthquakes (*32*). Comparison of injection depths for most states in the CEUS, excluding Mississippi, Indiana, West Virginia, and Alabama, is possible, as these data are more readily available than injection rates and pressures (table S1). Class II injection wells are permitted over a wide range of injection depths from 300 to 4000 m (fig. S14). The majority of both SWD and EOR wells inject between 300 and 1500 m (fig. S14, B and E). Wells associated with earthquakes also inject over a similarly wide range of injection depths (fig. S14, A and D). We find no clear evidence that increasing injection depth increases the likelihood that a well will be associated with seismicity; the proportion of both SWD and EOR wells associated with earthquakes does not increase with increasing injection depth (fig. S14, C and F). However, comparison of injection depths neglects the large variations in sediment thickness across the CEUS.

Using a map of sediment thickness across the CEUS (*37*), we estimate injection proximity to basement for all wells by subtracting injection well depth from the sediment thickness at the closest sediment thickness data point. The

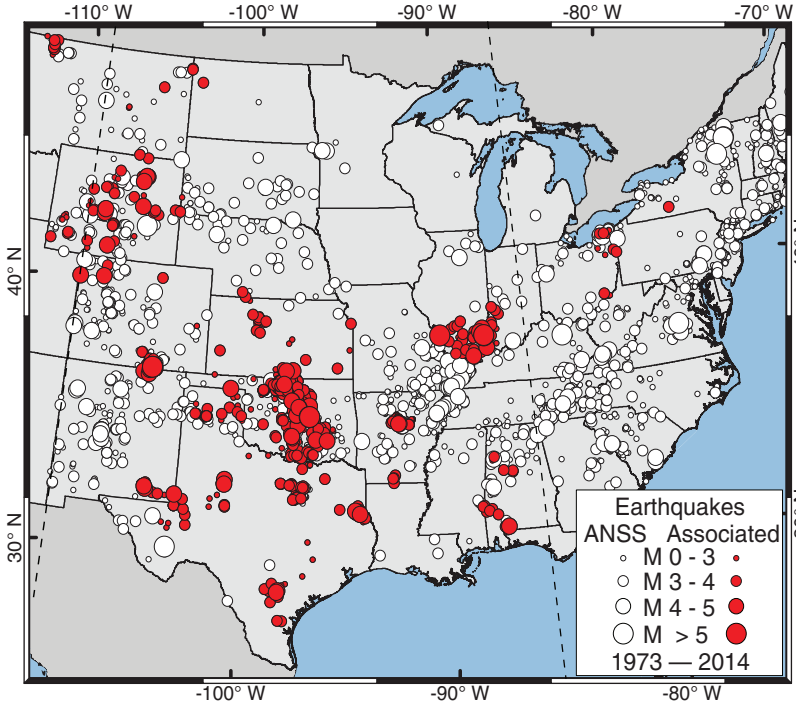


Fig. 2. Associated earthquakes in the CEUS from 1973 to 2014. Map showing the locations of $M \geq 0.0$ earthquakes in the ANSS ComCat earthquake catalog from 1 January 1973 through 31 December 2014. White dots denote earthquakes that are not spatiotemporally associated with injection wells. Red dots denote earthquakes that are spatiotemporally associated with injection wells. Following Ellsworth (*7*), the U.S. mid-continent is defined by the dashed lines inside of the greater CEUS.

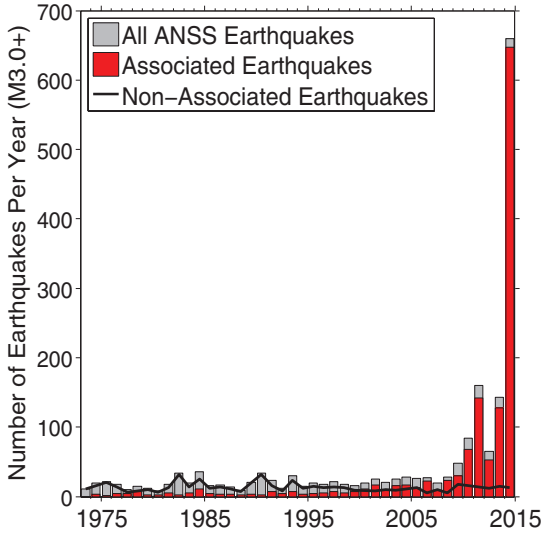


Fig. 3. Associated and nonassociated earthquakes per year in the U.S. mid-continent. The gray bars represent the number of $M \geq 3.0$ earthquakes per year in the U.S. mid-continent (Fig. 2) located by the networks of the ANSS ComCat earthquake catalog from 1 January 1973 to 31 December 2014. The red bars represent the number of earthquakes that are spatiotemporally associated with injection wells. The black line denotes the number of nonassociated earthquakes per year. Over the time period of the catalog, the number of nonassociated earthquakes per year has stayed roughly constant at 10 to 25 per year. Meanwhile, the number of associated earthquakes per year has risen from ~1 to 7 per year in the 1970s to 75 to 190 per year between 2011 and 2013 and >650 earthquakes in 2014.

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sediment thickness map was tested against known reference depths of crystalline basement and found to have errors in thickness up to ±15% (table S3). Thousands of wells in the CEUS inject fluid within 500 m of crystalline basement rock, but only a small proportion are associated with seismicity. When taking into account the error in basement depth over the CEUS region, we did not observe a significant correlation between a well's injecting near basement and earthquakes using a bootstrap resampling method (fig. S15). However, injection wells operating very far from basement, between 7 and 12 km vertically, exhibited an association rate near zero. We found similar results for both depth parameters using only well associations with earthquakes greater than *M* 3.0 (figs. S16 and S17). This finding supports the notion that detailed stratigraphic knowledge surrounding the injection interval is necessary to quantify the mechanistic linkage between injection and seismicity (*32*).

The lack of spatiotemporal association between injection and seismicity in several regions highlights the apparent influence of factors other than injection well operation. The San Juan Basin of New Mexico, the Williston Basin of North Dakota, the Michigan Basin, and extensive areas of the Texas and Louisiana Gulf Coast contain thousands of SWD and EOR wells that are not associated with seismicity (Fig. 1). In some of these regions, wells inject at rates similar to those in areas such as central Oklahoma, where large numbers of wells are associated with earthquakes. In the aseismic Michigan Basin, 30 wells operate at maximum injection rates greater than 200,000 bbl/month (fig. S18). Obviously, other factors in addition to high injection rate must play a role; the regional state of stress, fault size, fault orientation, the presence of fluid pathways between the injection point and faults, as well as other geologic factors must be examined to assess the potential for injection-induced seismicity (*4*).

Our analysis shows that injection rate is the most important well operational parameter affecting the likelihood of an induced seismic event in regions and basins potentially prone to induced seismicity. High-rate SWD wells are nearly twice as likely as low-rate wells to be near an earthquake. These high-rate wells perturb the ambient reservoir pressure by a larger magnitude and over a larger area than low-rate wells, thus increasing the likelihood that pressure changes will reach an optimally oriented, critically stressed fault. Previous studies have shown that high-rate wells exert greater influence on the extent and magnitude of reservoir and fault pressure perturbation (*24*). At the scale of our study, no other operational parameter was found to have a strong influence on the likelihood of association with an earthquake. The important distinction between operational parameters such as injection rate and cumulative injected volume shows the effect of the recent rise of new production methods and high-rate SWD wells. Thus, the oil and gas industry and regulatory bodies can use this operational parameter to lower the likelihood of earthquakes associated with injection wells.

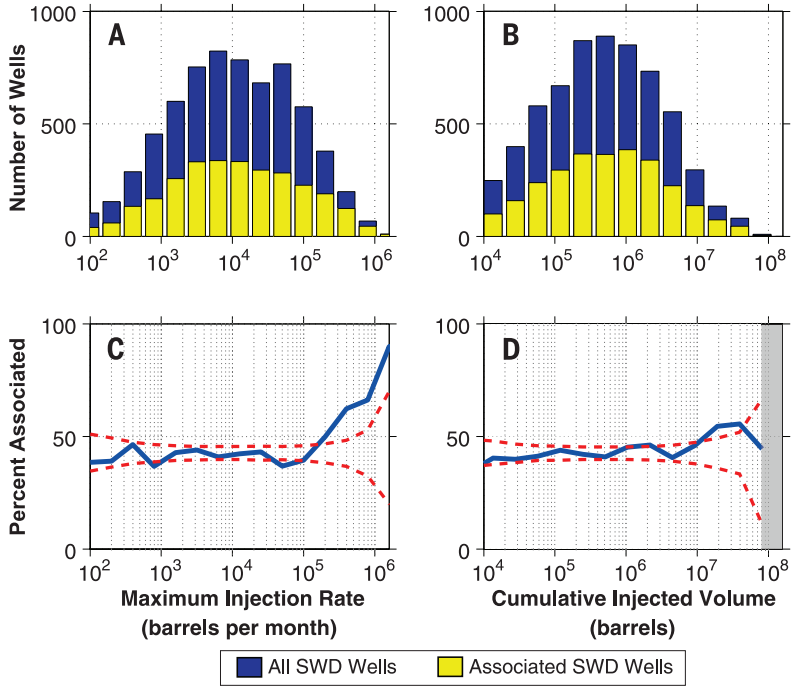


Fig. 4. Well operational parameter analysis. (**A**) Histogram showing the maximum monthly injection rate of salt water disposal (SWD) wells in Oklahoma, Arkansas, Colorado, and New Mexico. The blue and yellow bars show the number of wells operating at a given maximum monthly injection rate for all SWD wells (blue) and SWD wells spatiotemporally associated with an earthquake (yellow). (**B**) Histogram showing the cumulative injected volume at all wells in the same states as those in (A). The blue and yellow bars represent the number of wells operating at a given cumulative injected volume for all SWD wells (blue) spatiotemporally associated SWD wells (yellow). Injection data for Oklahoma were available from 1995 to 2013, for Arkansas from 1999 to 2013, for Colorado from 1999 to 2014, and for New Mexico from 1994 to 2014. (**C** and **D**) The percentage of all wells that are associated with an earthquake in each histogram bin is plotted as a function of (C) maximum monthly injection rate and (D) cumulative injected volume. The two dashed red lines represent the upper (95%) and lower (5%) confidence bounds in each bin generated by 10,000 bootstrap resamples and following the assumption that the rate of association is random. The shaded gray region of (D) indicates a lack of associated wells at the given volume. These data are also broken down state by state and for EOR wells in figs. S9 and S10.

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SUPPLEMENTARY MATERIALS

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Materials and Methods
Figs. S1 to S18
Tables S1 to S4
References (*38*–*46*)

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POLARON DYNAMICS

Long-lived photoinduced polaron formation in conjugated polyelectrolyte-fullerene assemblies

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The efficiency of biological photosynthesis results from the exquisite organization of photoactive elements that promote rapid movement of charge carriers out of a critical recombination range. If synthetic organic photovoltaic materials could mimic this assembly, charge separation and collection could be markedly enhanced. We show that micelle-forming cationic semiconducting polymers can coassemble in water with cationic fullerene derivatives to create photoinduced electron-transfer cascades that lead to exceptionally long-lived polarons. The stability of the polarons depends on the organization of the polymer-fullerene assembly. Properly designed assemblies can produce separated polaronic charges that are stable for days or weeks in aqueous solution.

In biological photosynthetic systems, energy cascade structures promote the spatial separation of photogenerated charges created at the reaction center, preventing their recombination. These energy cascade structures require close proximity of the electron donors and acceptors, on the scale of ~1 nm, and the corresponding electron transfer (ET) processes take only a few picoseconds (*1*). Similarly, photoexcitation in artificial organic photovoltaic (OPV) cells generates dissociated charges at a donor-acceptor interface on subpicosecond time scales. However, OPVs suffer a large degree of recombination because they rely on phase separation of the conjugated polymer donor and fullerene acceptor into domains on the length scale of 10 to 20 nm to facilitate efficient exciton diffusion and charge transfer (*2*, *3*). The high charge densities present in OPVs, coupled with the low dielectric constant of organic materials, favor carrier recombination before the charges can be extracted through external electrodes. If OPVs could be designed to use ET cascade structures that are reminiscent of photosynthetic complexes, it should be possible to greatly improve charge separation and reduce recombination losses (*4*).

Here we describe how molecular self-assembly can enable dissolved OPV materials (conjugated polymers and fullerenes) in aqueous solution to mimic the ET cascade structures of biological complexes and allow us to "spatially" control photogenerated charges. We demonstrate efficient long-time charge separation following photoexcitation: The ET cascade produces separated polarons that are exceptionally stable for weeks, a lifetime that is unprecedented for OPV materials. Although long polaron lifetimes have been observed in covalently linked donor-acceptor dyads and triads (*5*) and micellar structures (*6*), our use of standard organic photovoltaic materials sets this work apart. In addition, our use of self-assembly provides potential future advantages in reproducibility and scalability, both of which are major hurdles for conventional OPVs with kinetically controlled structures (*7*–*9*). Finally, the photoinduced charge separation we achieve takes place in water, opening possibilities for the "green" production of artificial photosynthetic devices.

The particular materials used in this study are a combination of a conjugated polyelectrolyte, poly(fluorene-alt-thiophene) (PFT) (*10*), and several regioisomers of the charged fullerene derivatives C_{60}-*N*,*N*-dimethylpyrrolidinium iodide [$C_{60}(PI)_n$], where n is the number of charged pyrrolidinium iodide groups (*11*) (Fig. 1, A to C). PFT is a water-soluble semiconducting polyelectrolyte whose bis-alkylated sp^3-hybridized fluorenyl carbon forms a wedge-shaped monomer that facilitates the assembly of the charged polymer into rod-like micelles (Fig. 1B); details of how this polymer assembles have been published previously (*10*). Because of the charged nature of the polymer, the electron acceptor(s) must also carry cationic charges to avoid heterocoagulation. The synthesis of $C_{60}(PI)_n$, depending on the reaction conditions, produced multiadducts with n ranging from 2 to 5, including multiple regioisomers for each n. To avoid confusion, we will refer to $C_{60}(PI)_n$ with n = 3 to 5 as "higher" adducts and fullerenes with n = 2 as "mixed-bis" adducts.

We achieved control over the solution-phase aggregation of these materials by exploiting the different solubility properties of the conjugated polyelectrolyte and charged fullerene derivatives. Mixed-bis adducts show limited solubility (without PFT) in aqueous solution, whereas higher adducts are water soluble at high concentration. This difference suggests that the mixed-bis adducts should coassemble in aqueous solution with PFT, a result we confirmed by cryogenic electron microscopy (cryoEM), small-angle x-ray scattering (SAXS), and luminescence quenching studies. CryoEM images of pure PFT, PFT:mixed-bis adducts, and PFT:high adducts

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High-rate injection is associated with the increase in U.S. mid-continent seismicity
M. Weingarten, S. Ge, J. W. Godt, B. A. Bekins and J. L. Rubinstein
(June 18, 2015)
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Editor's Summary

Making quakes depends on injection rates

Wastewater injection wells induce earthquakes that garner much attention, especially in tectonically inactive regions. Weingarten *et al.* combined information from public injection-well databases from the eastern and central United States with the best earthquake catalog available over the past 30 years. The rate of fluid injection into a well appeared to be the most likely decisive triggering factor in regions prone to induced earthquakes. Along these lines, Walsh III and Zoback found a clear correlation between areas in Oklahoma where waste saltwater is being injected on a large scale and areas experiencing increased earthquake activity.

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