APPENDICES……

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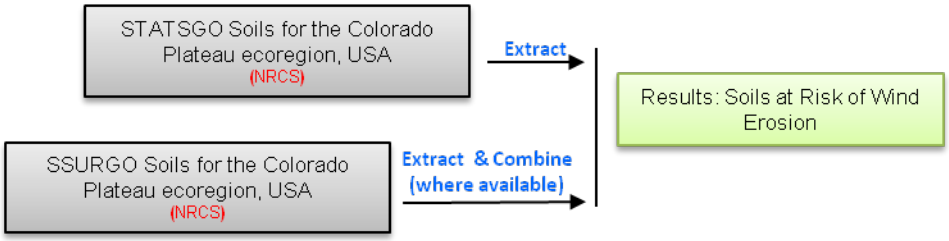
Appendix A – Colorado Plateau Management Questions

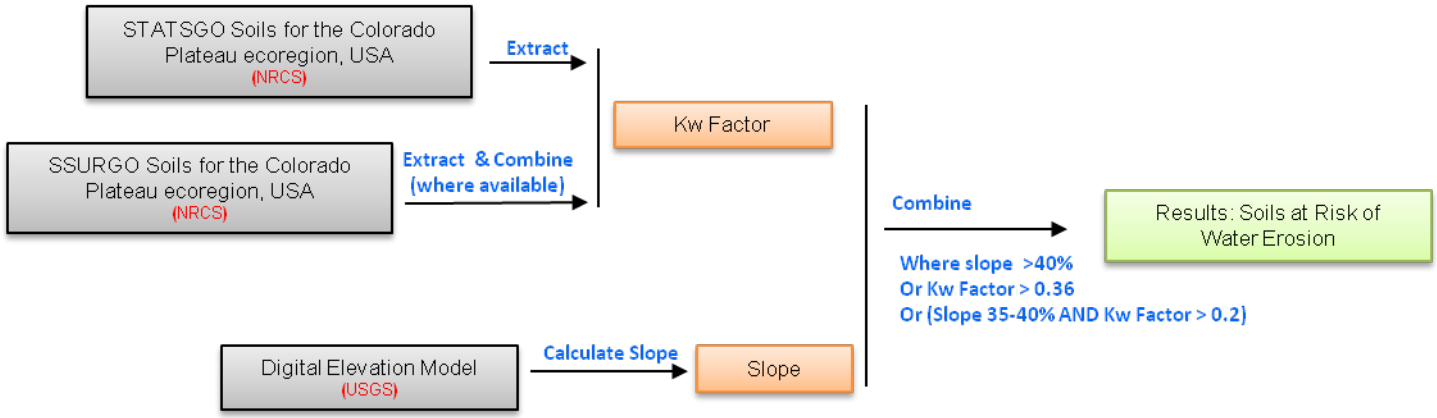
Organization of Appendix A

The following sources and results are provided for each management question: a conceptual model and/or a Process Model and a description of the analytical process (including source data) for each management question and results in the form of maps and other supporting graphics. Access to a data portal to examine the results in greater detail is available at the BLM website: http://www.blm.gov/wo/st/en/prog/more/climatechange.html.

A. Soils, Biological Crust, and Forage Management
MQ A1. Where are soils susceptible to wind and water erosion?

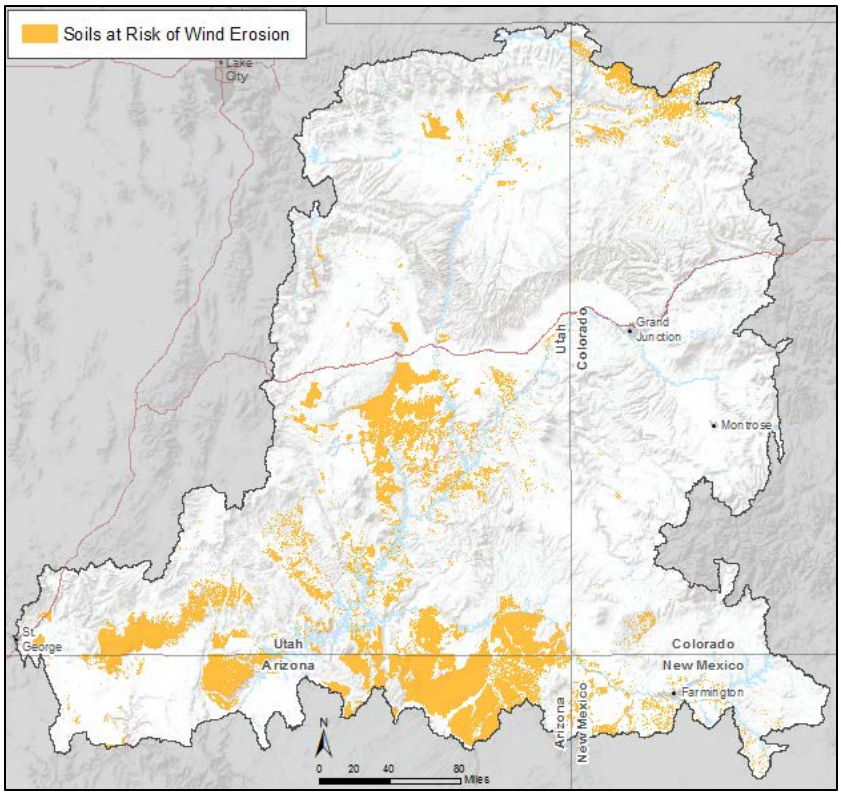
Process Model or Description

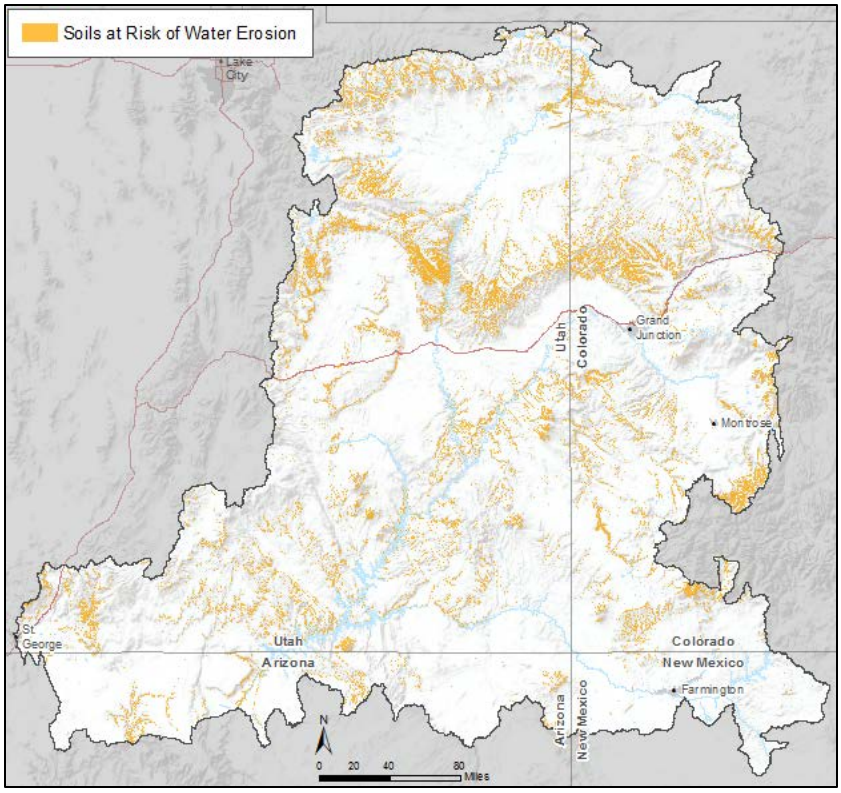




Results

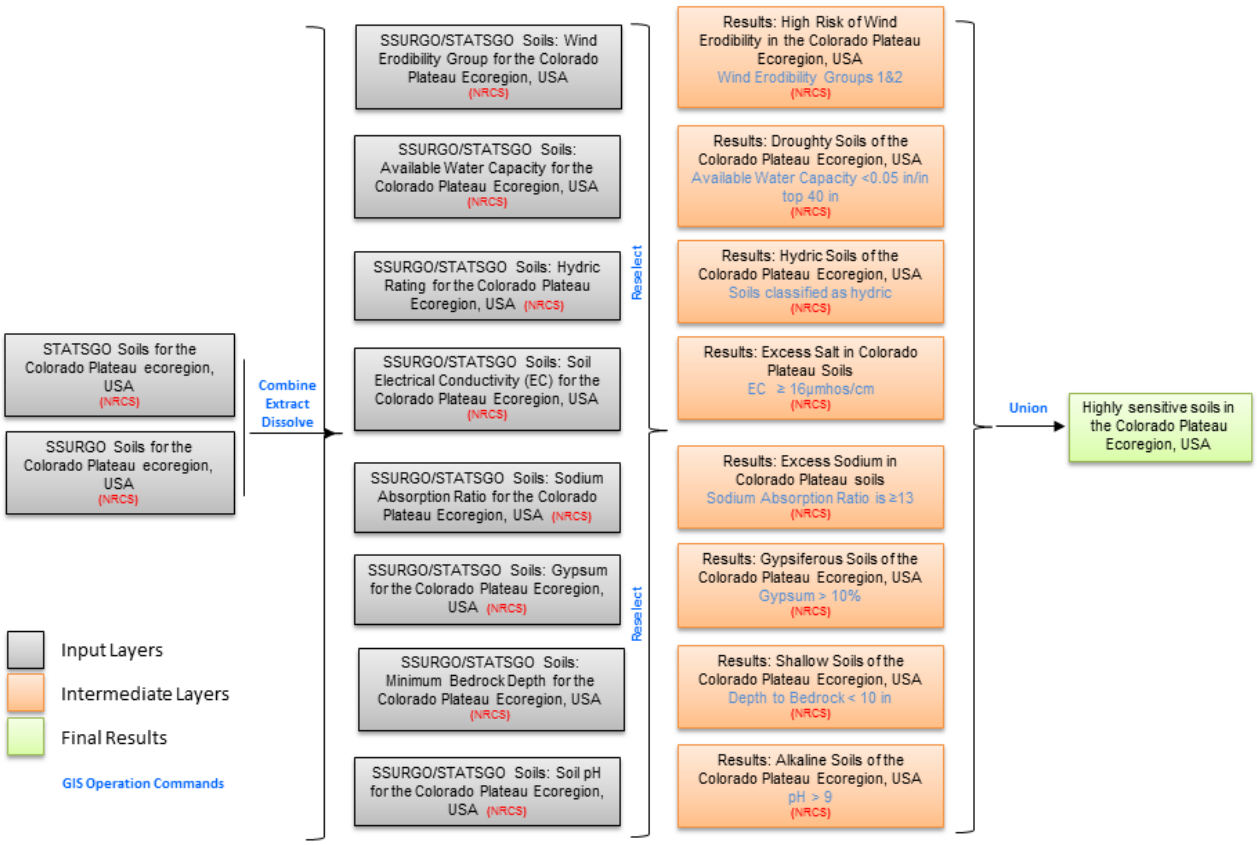
MQ A1. Where are soils susceptible to wind and water erosion?





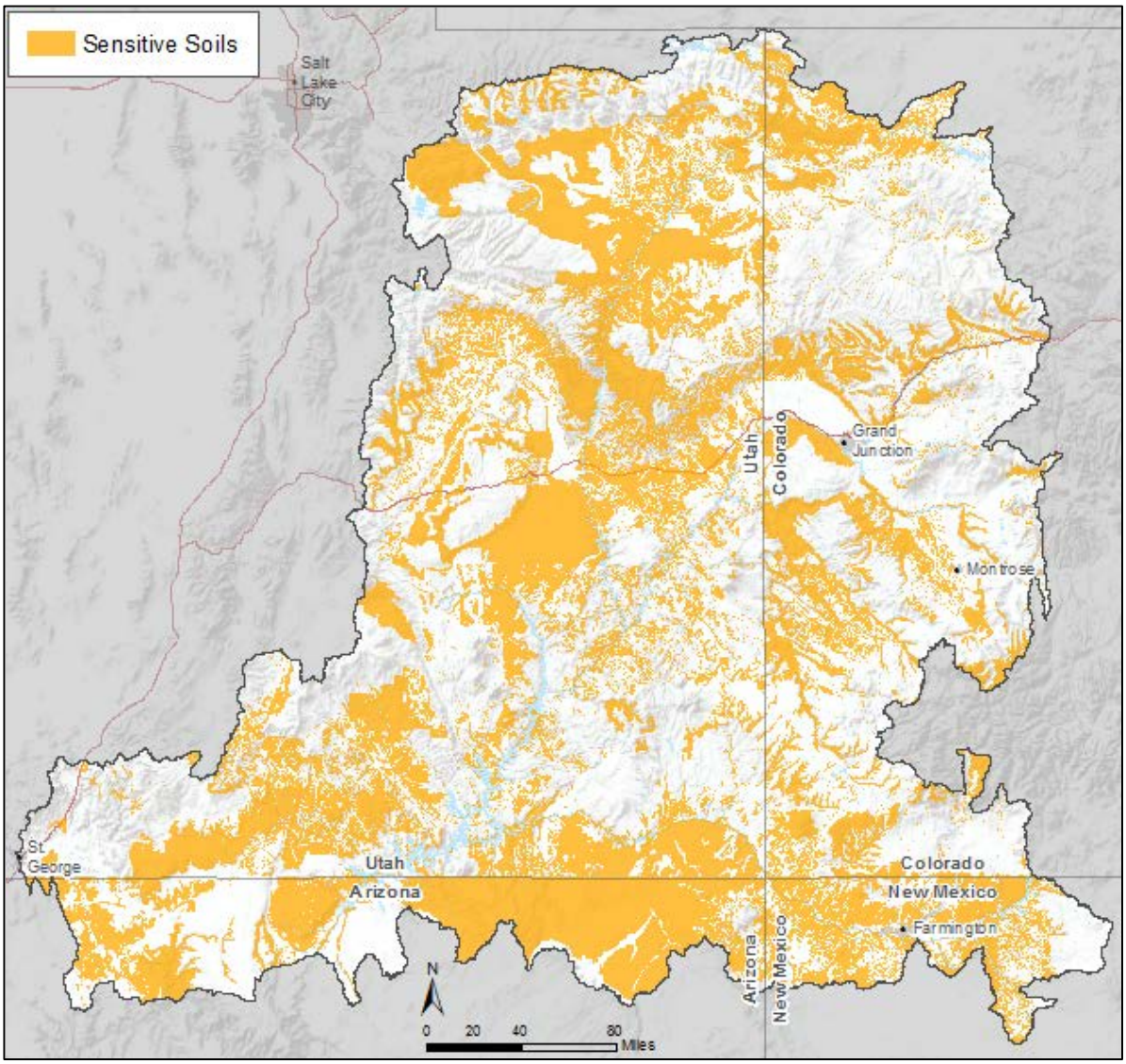
A. Soils, Biological Crust, and Forage Management
MQ A2. Where are sensitive soils (including saline, sodic, gypsiferous, shallow, low water holding capacity)?

Process Model



Results

MQ A2. Where are sensitive soils (including saline, sodic, gypsiferous, shallow, low water holding capacity)?



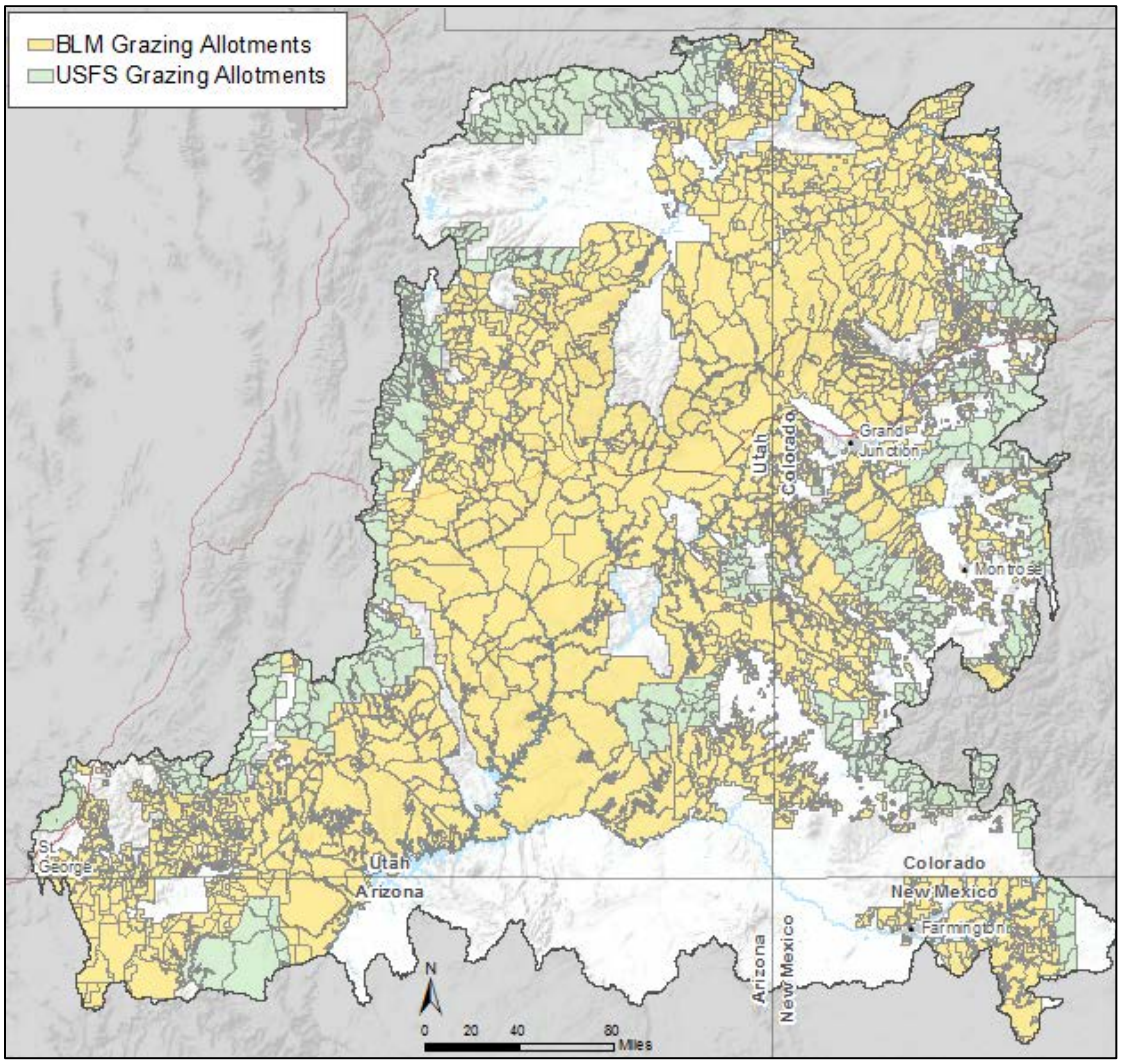
Note: Any individual soil type may be viewed individually as source data on date portal.

A. Soils, Biological Crust, and Forage Management
MQ A3. Which HMAs and allotments may experience significant effects from change agents including climate change?

Process Description

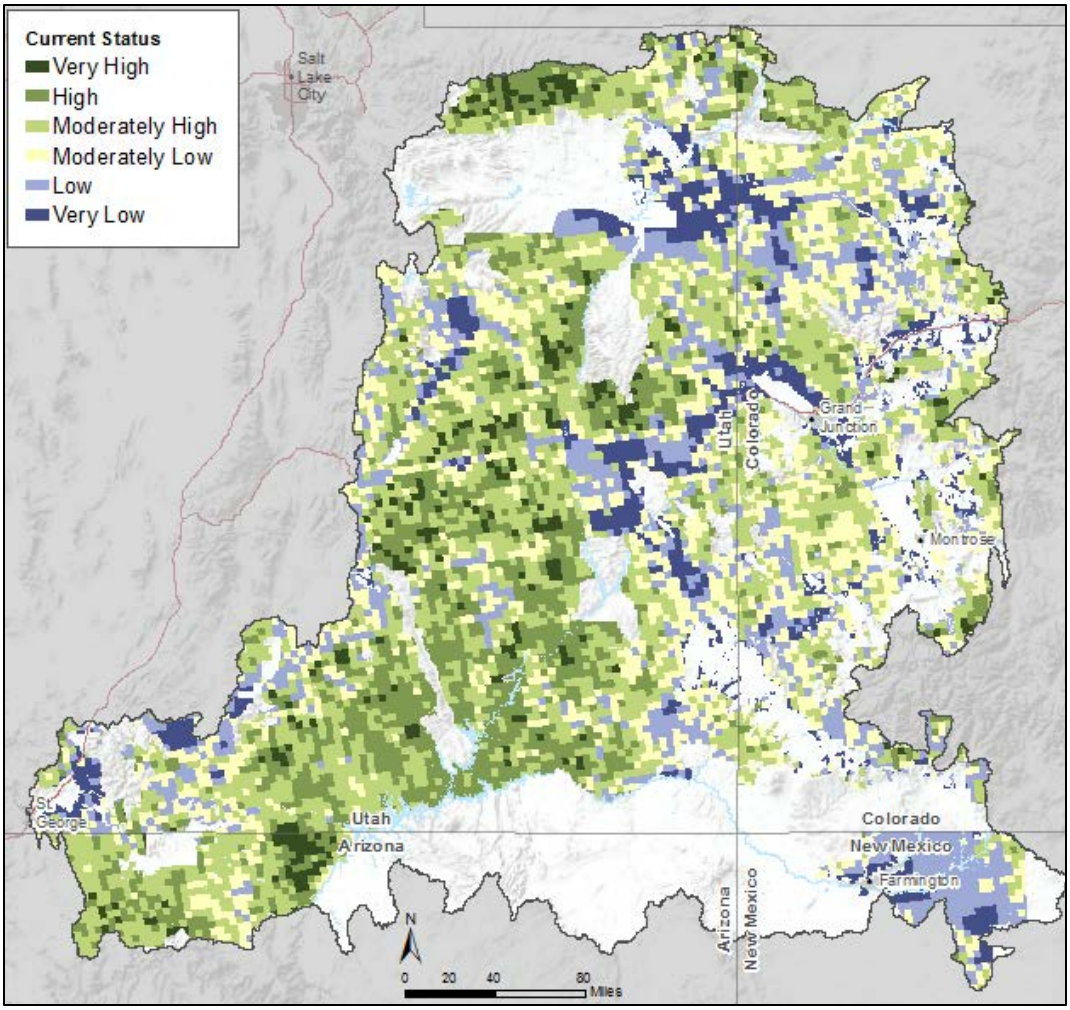
Allotments and HMAs were intersected with the combined results of current and near-term terrestrial intactness and long-term potential for climate change and energy development (see Appendix D for logic models).

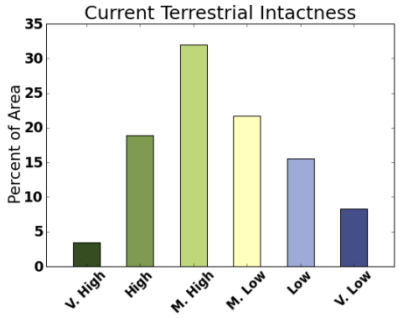
Results



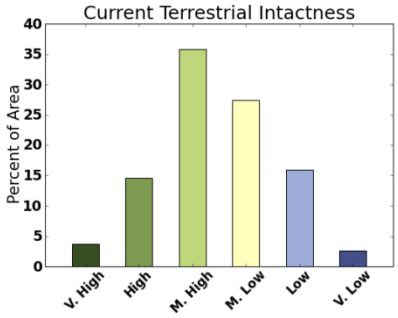
MQ A3. Which HMAs and allotments may experience significant effects from change agents including climate change?

Current Status of Allotments





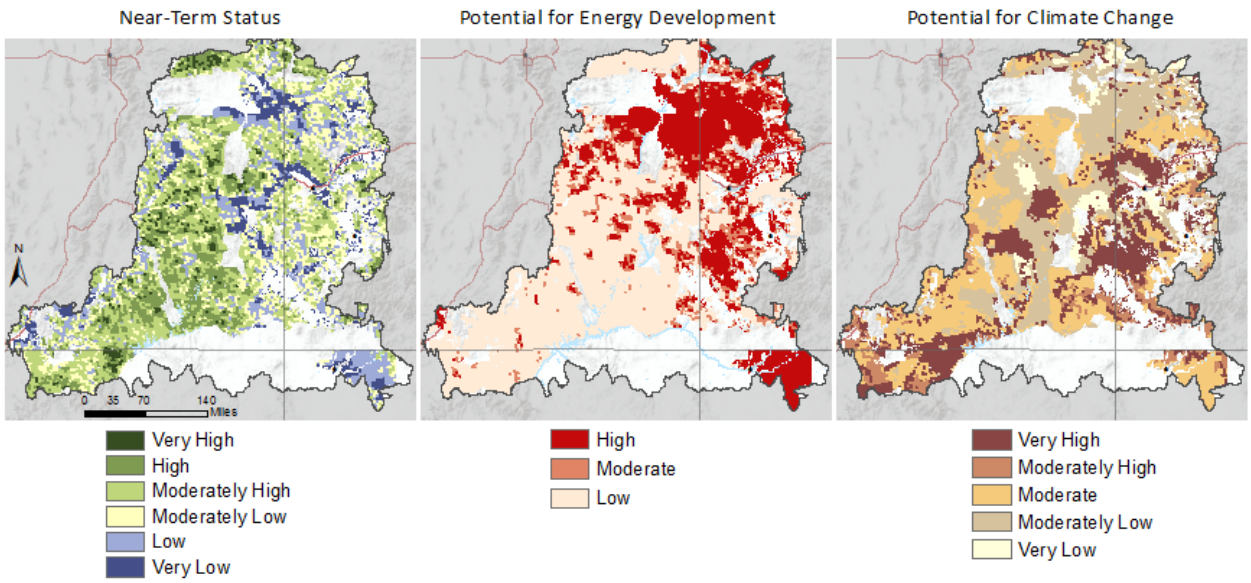
BLM Allotments



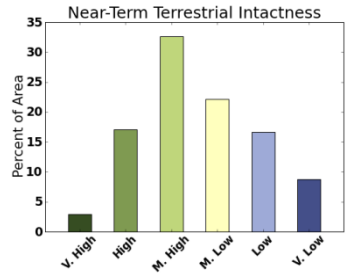
Forest Service Allotments

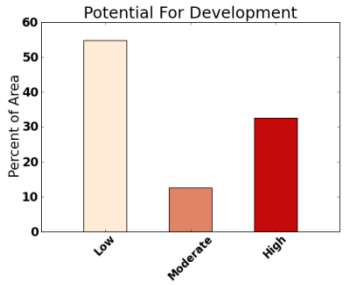
MQ A3. Which HMAs and allotments may experience significant effects from change agents including climate change?

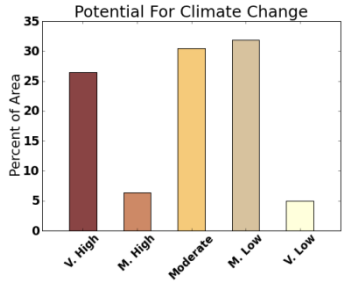
Allotments near-term future (2025) status, long term maximum potential energy development and potential for climate change (2060):



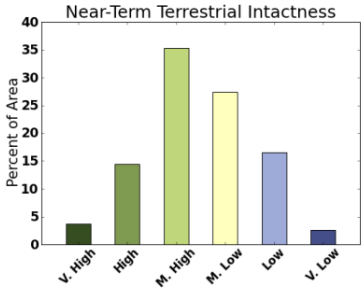
BLM Allotments

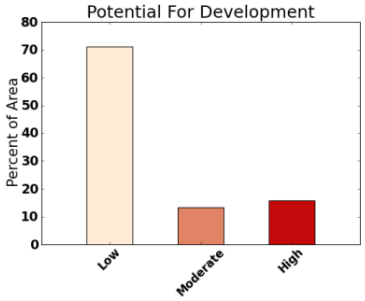


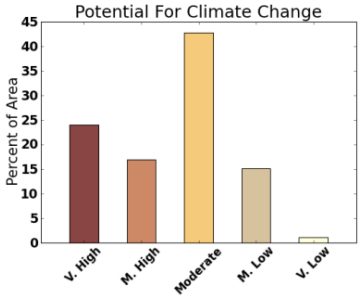




Forest Service Allotments

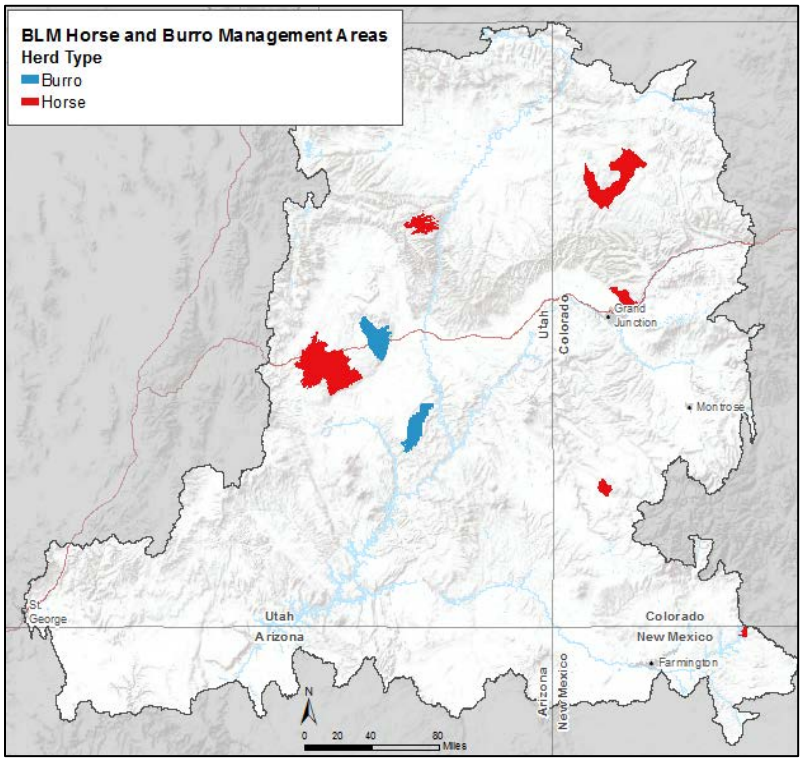


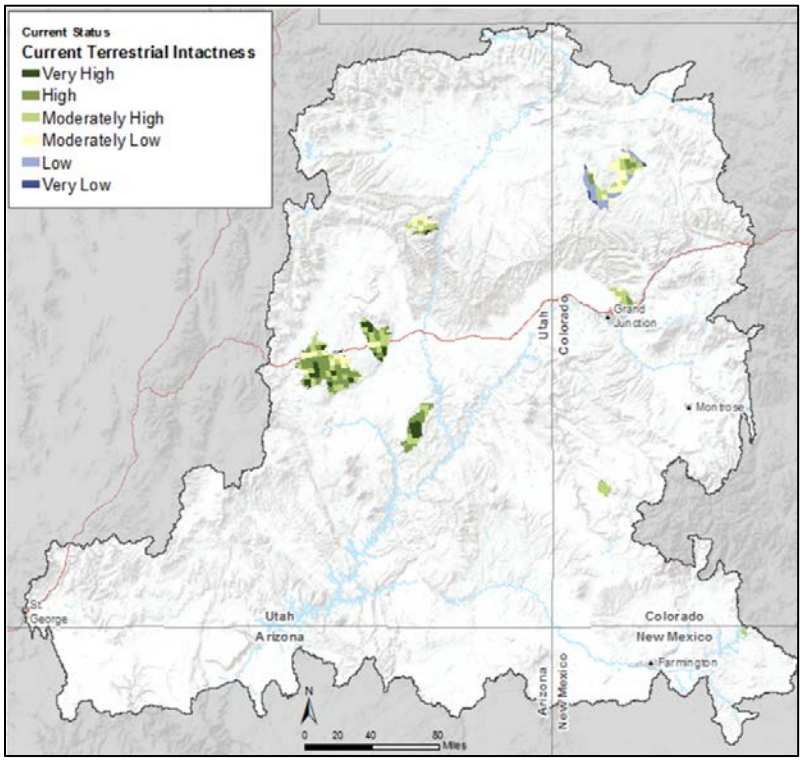


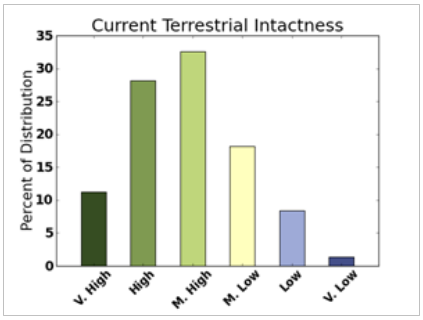


MQ A3. Which HMAs and allotments may experience significant effects from change agents including climate change?

Current Distribution and Status of Herd Management Areas (HMAs)

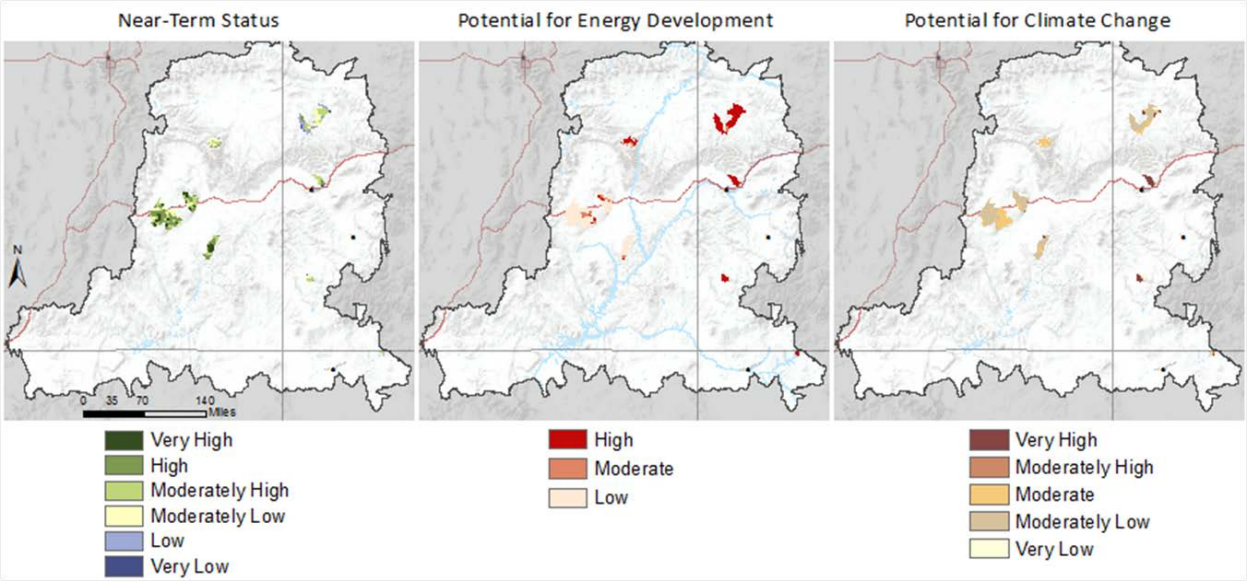


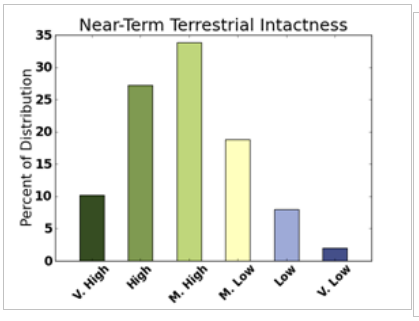


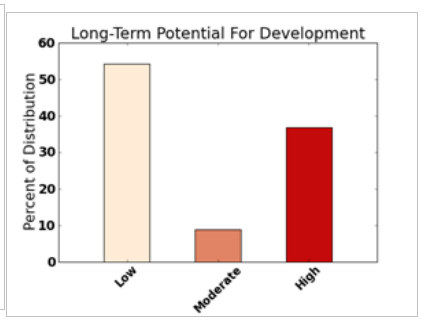


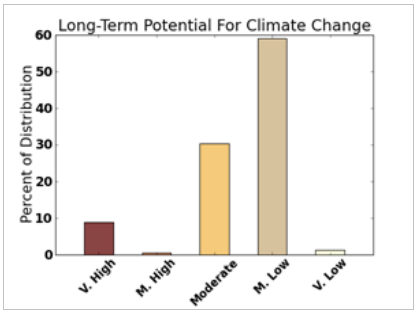
MQ A3. Which HMAs and allotments may experience significant effects from change agents including climate change?

HMAs near-term future (2025) status, long term maximum potential energy development and potential for climate change (2060):

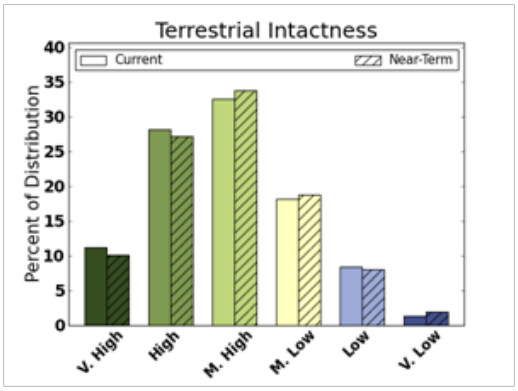








Current and Near-term future intactness



A. Soils, Biological Crust, and Forage Management
MQ A4. Where are soils that have potential to have cryptogamic soil crusts?

Soil Crust Conceptual Model

Biological crust forms in most ecological systems throughout the Colorado Plateau. There are five primary natural drivers (cyan boxes) that determine the extent and composition of biological crust including soil characteristics, precipitation, temperature, wind erosion, and condition and extent of natural vegetation.
Biological soil crust stabilize the soil surface as the combined community of cyanobacteria, mosses, lichens, and other organisms reduce or prevent soil surface erosion (Jones et al. 1997). Biological crusts serve as an important source of fixed carbon (Beymer and Klopatek 1991); crusts also fix nitrogen (Belnap 1995), inhibit invasive seed germination (Larsen 1995), help retain soil moisture (Belnap and Gardner 1993), and stabilize soils (Belnap and Warren 1998). Loss of soil crust is both a component of and accelerator of desertification (Belnap 1995). Biological crusts are sensitive to even relatively minor soil disturbances. Surface disturbance by humans, livestock, and machines have affected a large proportion of crust cover throughout the Colorado Plateau. Biological crust disturbance leads to increased soil erosion from wind and water, which adds to the difficulty for crust reestablishment as soil crust is sensitive to burial. Besides mechanical disturbance, biological soil crust responds to the condition of the native vegetation—degraded natural ecosystems usually means degraded soil crust—and it does not effectively resist the expansion of non-native invasive species.

The major change agent affecting this ecological system covered in the REA process is Development (based on current and projected future extent of urban land cover). Overall landscape intactness, which includes development from all sources (urban, agriculture, energy, roads, and recreation), invasive species, and habitat fragmentation, is used to describe the regional environment that contains this ecosystem type. Climate change projections (including precipitation and temperature changes as well as MAPSS modeling outputs are also used to predict where natural plant communities that may contain biological crust may be under significant climate stress.

References

Belnap, J. 1995. Surface disturbances: Their role in accelerating desertification. *Environmental Monitoring and Assessment* 37:39–57.

Belnap, J., and J.S. Gardner. 1993. Soil microstructure of the Colorado Plateau: the role of the cyano-bacterium *Microcoleus vaginatus*. *Great Basin Naturalist* 53:40–47.

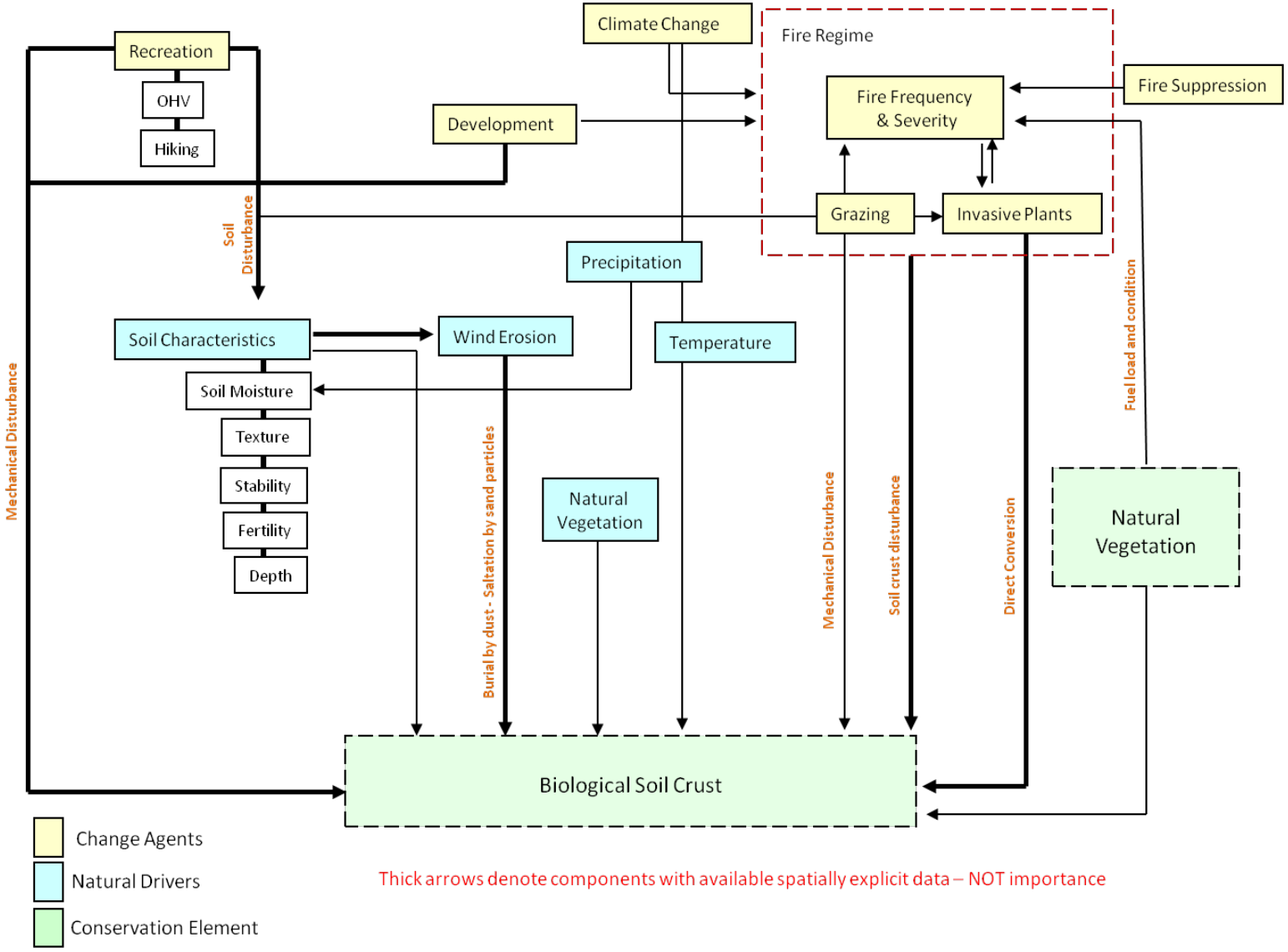
Belnap, J., and S. Warren. 1998. Measuring restoration success: a lesson from Patton's tank tracks. *Ecological Bulletin* 79: 33.

Beymer, R.J., and J.M. Klopatek. 1991. Potential contribution of carbon by microphytic crusts in pinyon-juniper woodlands. *Arid Soil Research and Rehabilitation* 5:187–198.

Jones, C.G., J.H. Lawton, and M. Shachak. 1997. Positive and negative effects of organisms as physical ecosystem engineers. *Ecology* 78: 1946–1957.

Larsen, K.D. 1995. Effects of microbiotic crusts on the germination and establishment of three range grasses. Unpublished thesis, Boise State University, Boise.

Biological Soil Crust Conceptual Model



Biological Soil Crust Model Description

A potential biological crust model was generously provided to this REA by M.A. Bowker, U.S. Geological Survey. Predictor variables included: annual precipitation and seasonality (PRISM), annual maximum and minimum temperature (PRISM), soils data (Natural Resources Conservation Service), surficial geology data, and Digital Elevation Model (DEM) data. Model outputs were generated at 800 m resolution.

For REA final results, we removed impervious surfaces (from NLCD Impervious Surfaces 2006) and developed and intensive agriculture (from LANDFIRE EVT v1.1) from early and late successional crust potential predicted by Matt Bowker.

Below is an insert by Matt Bowker and Terry Arundel describing the predicted surface for the soil crust model:

Maps of Potential Biological Crust Abundance on the Colorado Plateau

Matthew A. Bowker and Terry Arundel
US Geological Survey, Southwest Biological Science Center, Flagstaff, Arizona

Introduction

These data layers indicate the *potential* quantitative cover of biological crusts, and major constituents (mosses, lichens, dark cyanobacterial crusts) across the entire Colorado Plateau. The product is intended to assist BLM and its contractor, Dynamac Inc., in treating biological crusts as a conservation element in the Colorado Plateau Rapid Ecoregional Assessment.

What this work <u>will</u> do:

At the scale of the entire Colorado Plateau, we provide a spatially explicit estimate of the crust abundance that would likely exist if the site were in a "least-disturbed" state. Least-disturbed indicates an ecosystem state existing under current or recent climate conditions, that has been as minimally affected by disturbance as possible, given the context of widespread current and historical grazing. This state may or may not be equivalent to a historical reference condition; there is simply no information to know. Examples of least-disturbed sites include: 1) sites in National Parks where grazing has been excluded for some time, 2) never-grazed relicts, 3) Range exclosures, 3) Sites within grazed landscapes which are distant from water and/or high quality forage, or are geographically isolated.

What this work <u>will not</u> do:

This work will estimate and map the <u>potential</u> crust abundance, but will not map the current, existing crust abundance. Remote sensing is the only practical way to conduct the latter at such a large scale.
This work will be useful for regional scale analyses but may or may not provide a reliable basis for determining the status of a particular location (e.g. a hectare plot). Due to time and budgetary constraints, we are forced to partially rely on relatively low resolution model inputs (e.g. PRISM climate data). This may compromise the accuracy of model predictions at finer spatial scales.

Materials and Methods

Ecoregional biocrust database

An integrated dataset of samples from around the Colorado Plateau, and its northern, southern and eastern ecotones was assembled (Table 1). All sites were in least-disturbed condition at the time of sampling. Seven data sources were used. Sites from datasets by Bowker et al. were carefully selected based upon known or inferred disturbance history. Other data sources are from currently ungrazed areas in National Park Service units. In addition to being ungrazed we screened out sites which may be in a persistent annualized state (>5% exotic annuals) and interviewed data collectors about the reasonability of including these sites. There are 682 total records in all—593 contain data on total crust cover, and 502 contain data on soil stability. In addition, 259 contain primary soil data collected in association with the crust surveys; these data include soil texture, $CaCO_3$ and gypsum content.

We compiled 681 individual records from 5 different datasets to construct models of potential biocrust abundance. All datasets met the following requirements for inclusion: 1. data represented ecosystems in a low disturbance state. These included samples from National Parks, retired grazing allotments, geographically isolated areas including mesa tops, and samples within a more heavily grazed matrix that had escaped recent disturbance due to distance from water, roads, or adequate forage; 2. datasets were favored that had one of the authors personally involved (Bowker et al. 2005, Bowker et al. 2006, Bowker & Belnap 2007) or sufficiently familiar to be confident in the data.

Table 1. Summary of integrated dataset of quantitative biological crust data. Numbers refer to number of samples in each category. (M) denoted that soils stability values were modeled based on crust and other site characteristics; otherwise they are measured on site.

Data source	Location	Soil data	Dk. cyano	Moss	Lichen	Total crust	Chlor. a	Soil stability
Bowker et al. 2006	Grand Staircase-Escalante NM & vicinity	114	114	114	114	114	113	113(**M**)
Bowker & Belnap 2007	Walnut Cyn NM & vicinity	11	11	11	11	11	11	11
	Wupatki NM	25	25	25	25	25	25	25
	Sunset Crater NM	4	4	4	4	4	4	4
	Verde Valley, Arizona	11	11	11	11	11	11	11
	Other N. Arizona	13	13	13	13	13	13	13
Bowker et al. 2005	Canyonlands & vicinity	38		38	38			
	Dinosaur NM	8		8	8			
	Natural Bridges NM	8		8	8			
	Glen Canyon NRA	23		23	23			
	Other (Hovenweep NM Arches NP)	4		4	4			
Coles et al. 2010	Arches NP		90	90	90	90		
Miller et al. unpub	Canyonlands NP					101		101
NPS I&M								
NCPN	Canyonalnds NP		62	62	62	62		62
	Capitol Reef NP (retired allot's)		21	21	21	21		21
	Black Canyon/Curecanti (retired allot's)		17	17	17	17		17
	Dinosaur NM (retired allot's)		16	16	16	16		16
SCPN	Chaco Cyn CP		16	16	16	16		16
	Mesa Verde NP		20	20	20	20		20
	Petrified Forest NP		62	62	62	62		62
	Grand Canyon NP		10	10	10	10		10
Totals		259	492	573	573	593	177	502

Modeling

Using these existing data, we prepared regression tree models (CART) that estimate potential abundance of biological crusts on the Colorado Plateau landscape.

Predictors:

Annual precipitation and seasonality: The PRISM model provided information at an 800m grid cell size regarding long-term (1971–2000) annual average precipitation. Using their monthly normals, we derived the proportion of the total that falls from July–September, an index of the relative import of the summer monsoon.

Annual maximum and minimum temperature: The PRISM model also provided information at an 800m grid cell size regarding annual average maximum and minimum temperature, the July maximum, and the January minimum as descriptors of temperature extremes.

Soils data: The Natural Resource Conservation Service (NRCS) in Utah, and private contractor Dynamac, Inc. oversaw the production of an ecoregional soil survey map based upon NRCS SSURGO data. This entailed joining numerous individual surveys into a single shapefile and database. The process was conducted by NRCS for the state of Utah, and Dynamac's subcontractors oversaw the same process in Arizona, New Mexico, and Colorado. Another, lower resolution national database, STATSGO, was used to fill holes in the SSURGO coverage. Because soils vary on such fine scales, reliance on higher resolution information was key. One cost of this approach is that soil surveys are conducted and mapped in a piecemeal fashion over decades, and outputs do not edgematch. Nonetheless it is the best high resolution soil data available.

From this database, we extracted and mapped 6 soil property indicators: $CaCO_3$, % gypsum, sodium adsorption ratio, % sand, % clay, and the plasticity index. These data were rasterized at a 30m resolution.

Geology Data: We also used a seamless geology map initially prepared by Dynamac, Inc. Because geological codes differ by state, we reclassified them into a simpler system based upon geological substrates represented in the integrated dataset. Groupings are based upon composition of rock (e.g. limestone, shales, sandstones, etc.), age (e.g. Permian, Jurassic, etc.) and were also informed by past experience (e.g. distinction of Kaiparowits from other cretaceous sandstones).

Geology data aggregations:

Alluvial = Qa, Qs, Qao

Basalt = QTb, Qtv, Qb

Chinle = TR2, TRc

Cretaceous SS = Kch, K1, Kjdj, Kjdw, Kdb

Cretaceous SH = Kls, K2, Km

Eolian = Qe

Jurassic SS = J1, J2, Jmwe

Kaiparowits = K3

Moenkopi = TRm, TR1

Navajo = JTR, JTRgc

Permian LS = Pkt, Pp

Permian SS = Pc, Pct, PNP

If a geological substrate was not encountered in the training data, it was treated as "other" in the modeling and mapping process.

DEM data:

We acquired 30m resolution digital elevation models, and derived slope and aspect from them.

Resolution:

Although there were two original data resolutions, 30m and 800m, we snapped all rasters to a common grid (that of the DEMs) to avoid topological problems. The higher resolution was necessary to avoid losing important detail in many datasets, and regrettably the 800m resolution is the best available for climate data. Resampling 30m data to 800m in nonsensical in this case.

Regression trees:

Using these input data, we constructed CART models of various types of crust cover. Crusts organisms can be conveniently grouped into dark cyanobacterial crust cover, moss cover, and lichen cover. It can be instructive to group these data in various ways such as total late successional crusts, which is the sum of all three, and total moss and lichen cover. We also modeled light crusts which refers to physical crusting (with some biological colonization) to biological crusting by non-pigmented cyanobacteria. Whereas moss and lichen cover is fairly unambiguous, we expected some observer bias in the other variables in the various datasets. Chlorophyll *a* (a cyanobacterial biomass indicator) was available for some of the data. Finally, soil stability using the Herrick soil stability kit which measures water stable aggregation on a scale of 0–6, was available in many cases.

We attempted to model all of the crust variables as a function of all of the above predictor data. Soil stability was modeled as a function of the various classes of crust cover, geology, and the six soil properties. We used one surrogate, which allows splits to be made on alternatives if a case is lacking a measurement of a predictor. We allowed the minimum size of a parent node to be 30 cases. To select the best tree we conducted a 25-fold cross validation, and pruned based upon the standard error rule. Cross validation allows an estimate of "cost", and a pseudo-R^2 estimating the proportion of variance the model would explain if confronted with new data. The standard error rule selects the simplest tree which has a cost within 1 standard error of the lowest cost tree. Another measure of model quality is the internal R^2, which measures how much variance the model explains in the training data. In the case of dark cyanobacteria, no splits were found using the standard error rule, thus we relaxed this constraint and built the lowest cost 2-node model. Because this modeling procedure is hierarchical, initial splits partially define which subsequent splits are selected; the saturated model may or may yield the best model. We systematically withheld related predictors (e.g. geology vs. the soil variables, annual temperature extremes vs. monthly temperature extremes) in an attempt to find lower cost models without greatly increasing complexity.

When our best tree was selected we considered this our "primary" model. Primary models were selected for total late successional crusts (moss + lichen + dark cyanobacteria), moss + lichen, lichens, mosses, dark cyanobacteria, light cyanobacteria, and soil stability. Several of our response variables can be estimated in more than one way, either directly through regression tree modeling, or indirectly using simple raster calculations based upon multiple mapped regression tree outputs. For example, it is possible to model late successional crusts (total moss + lichen + dark cyanobacteria) directly using regression tree analysis. Another approach might be to model these three components independently and sum the outputs. A third approach might model dark cyanobacterial crusts and total macrophytes (moss + lichens) directly and sum these outputs. *A priori*, there is no way of knowing which approach would yield the best predictions. For total late successional crusts (moss + lichen + dark cyanobacteria), moss + lichen, lichens, mosses, and dark cyanobacteria we produced 2 alternative models each based upon these simple arithmetic operations. We consider these "secondary" models. No secondary models were produced for light cyanobacteria or soil stability.

Multi-model inference:

Again, for total late successional crusts (moss + lichen + dark cyanobacteria), moss + lichen, lichens, mosses, and dark cyanobacteria, we devised a way of using primary and secondary models together to draw inference. All models contain some semblance of "truth" and different models may contain unique information (Burnham and Anderson 2002). We used multiple models as terms in multiple regression models, obtaining slope estimates for each of them. To select the best regression model we selected from all 8 possible models using Akaike's Information criterion. The best models always used the primary model in addition to at least one secondary model as terms. This can be considered a simplistic form of "boosting" (Elith et al. 2008). These multi-model outputs are considered our "final" models.

Results

We deliver twelve raster products. The following naming conventions are used:

li = light cynaobacteria

d = dark cyanobacteria

m = mosses

l = lichens

ml = mosses + lichens

mld = mosses + lichens + dark cyanobacteria

stability = soil stability

Both primary and final grids are provided, the final grids being preceded by "fin". In the cases where they are available we recommend use of final models over primary models. Secondary models are not provided to avoid confusion among users, and because they are less useful, and could easily be produced from primary models if desired. They can be provided on request.

Overall our approach was able to generate useful models for several parameters related to biocrust development and function. Predictive value of the models ranged from very high (light cyanobacterial cover and surface soil stability), to moderate (late successional crusts, total moss, total lichen, and total moss + lichen), to poor (dark cyanobacterial crusts).

Primary models:

Late successional crust cover *(moss + lichen + dark cyanobacterial cover):*

We constructed a 9 node model for late successional crust elements, primarily based upon monsoon importance, soil gypsum, and geology (**Figure 1f**). Our model explained 47% of the variation in the data. Based on cross-validation our best estimate of predictive power in new data is R^2 = 0.27.

Total moss + lichen cover*:*

Total moss + lichen cover was also described in a somewhat more successful 7 node model (**Figure 1e**) based primarily on soil gypsum and monsoon importance. Our model explained 46% of the variance in the data, and 36% when confronted with new data during cross validation.

Total moss

A four node model predicts total moss cover (**Figure 1c**). Variables related to temperature extremes were the most important predictors. This model explained 26% of the variation in the training data, and 20% when confronted with new data during cross-validation.

Total lichen

An equally simple but somewhat more successful model used four nodes to predict total lichen cover (**Figure 1d**). In descending order, the splits were based upon soil gypsum, temperature minimums, and monsoon importance. This model explained 36% of the variation in the training data, and attained an R^2 of 0.28 based on cross-validation.

Dark cyanobacterial crust cover

Based on an analysis of cost versus complexity and the 1 standard error pruning rule, we failed to generate even a single split in the dark cyanobacteria data. To ensure that we had a model with some weak predictive power, we forced a two node solution (**Figure 1b**). This split was based upon geology. Only 10% of variance was explained in training data, and 7% in validation data. Weak performance may be related to observer differences in the various datasets.

Early successional crusts (light cyanobacterial and some physical crust cover)

In contrast, our 9 node model of light cyanobacterial cover (**Figure 1a**) performed exceptionally well. Again monsoon importance was crucial, the first split, but this model also invoked 4 other predictors. About two thirds of the variance (67%) in the training data was explained. Validation performance was exceptionally good, capturing 53% of the variation in withheld data. We noted one idiosyncrasy of this model, that substrates coded as “chinle” in the geology dataset displayed relatively high values. “Chinle” encompasses bentonitic shales that support little true cyanobacterial crusting, in addition to sandier substrates that do support cyanobacteria. These bentonitic surfaces do tend to exhibit a thin physical crust which may be recorded by some observers as biocrust. Overall this appears to be a good model but users should note that predictions for chinle shales may be inflated.

Surface soil stability

The soil stability model was another of our most successful models. It is based upon eight nodes (**Figure 1g**). Late successional crust cover is the most important predictor, being invoked in the first split, and in three of the other splits. Variance explained in both training and validation is high, at 63% and 50%, respectively.

Multi-model inference

Several response variables can be modeled using more than one approach. A user could use the best performing model, the most direct modeling procedure, or draw information from multiple models simultaneously. Multi-model inference is powerful because the samples of one model that are difficult to explain may be explainable by another model.

In the case of the various types of biocrust cover, the direct approach to modeling was the most informative in all cases, but modeling only with the primary model was never selected as the best model; secondary models were invoked in all cases. In three of five cases the saturated model (using one primary term and two secondary terms) was the best model. Most cases exhibit substantial improvement in the variance explained in the training data. Users will note that in some of these final models, negative values are possible. These values should be interpreted as ones very near zero, and in any case are expressed only in very small portions on the output maps.

The equations appear below:

1. Response MLD

Intercept: -2.956984

Slope (mld primary model): 0.7125703

Slope2 (m + l + d): 0.5700944

Internal R^2 = 0.46

IF IT IS DESIRABLE TO REDUCE CRUST COVER TO ONE VARIABLE, we recommend using this model (finmld);. These are the most visible and highly functional crusts.

2. Response ML

Intercept: -0.578821

Slope (ml primary model): 0.4868865

Slope2 (m + l): 0.326629

Slope3 (mld – d): 0.2549641

Internal R^2 = 0.48

3. Response L

Intercept: 0.1215443

Slope (l primary model): 0.5048521

Slope2 (mld – m - d): 0.1638832

Slope 3 (ml – m): 0.2476273

Internal R^2 = 0.42

4. Response M

Intercept: -0.315065

Slope (m primary model): 0.7102625

Slope2 (mld – l - d): 0.1118507

Slope3 (ml – l): 0.1987241

Internal R^2 = 0.36

5. Response D

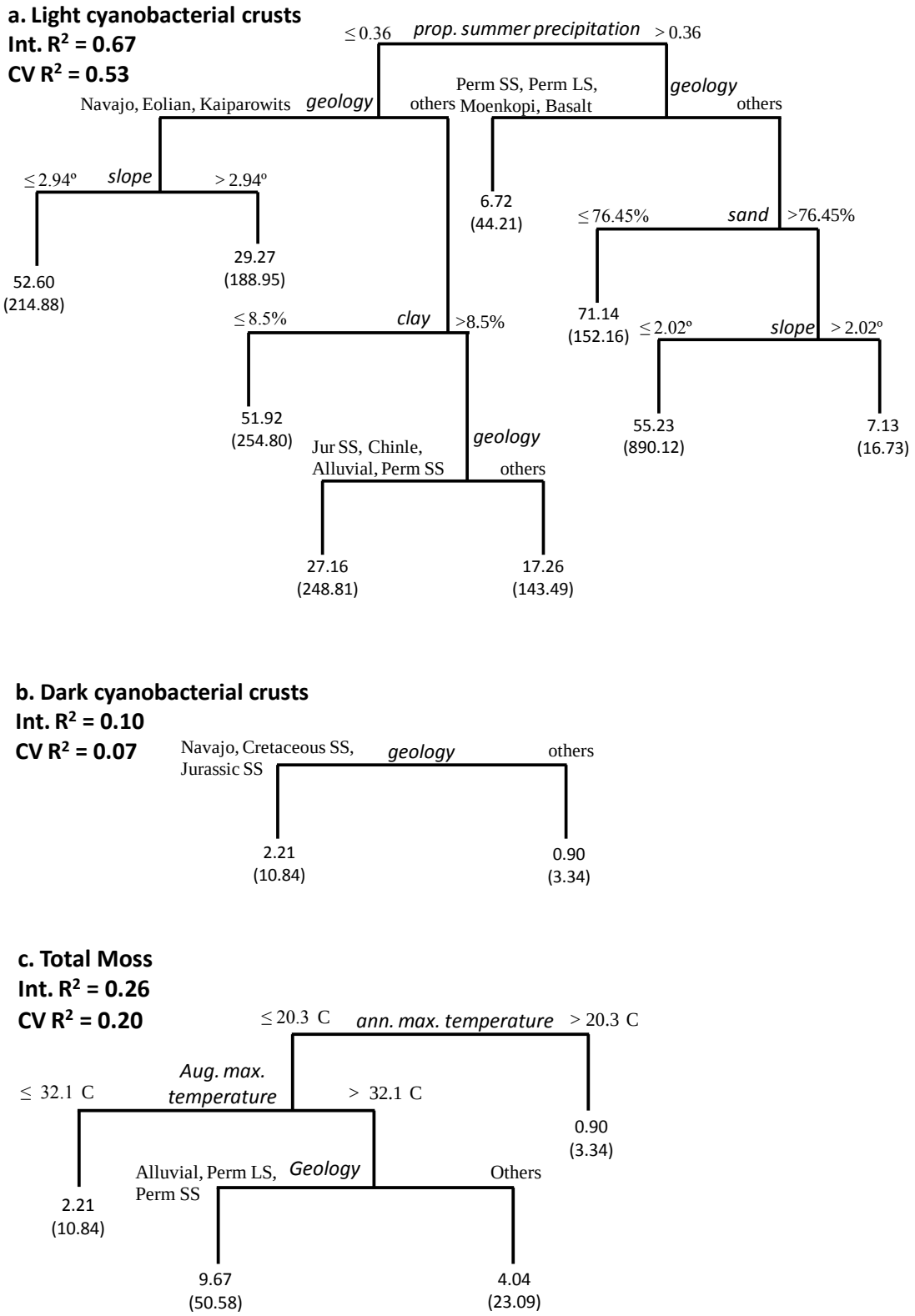
Intercept: -0.9187871

Slope (d primary model): 0.8590865

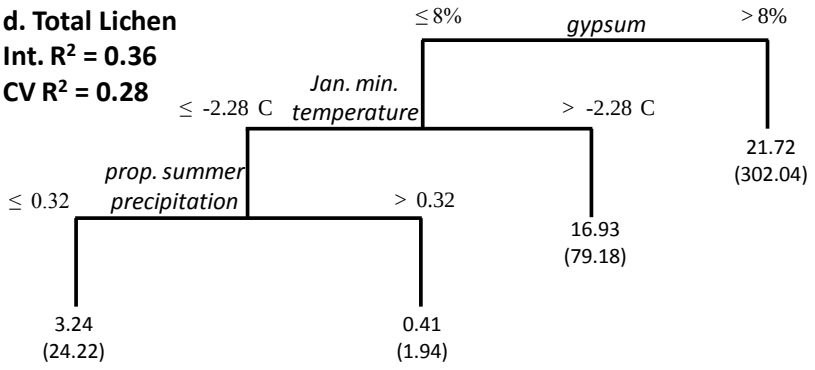
Slope2 (mld – l - m): 0.3137156

Internal R^2 = 0.19

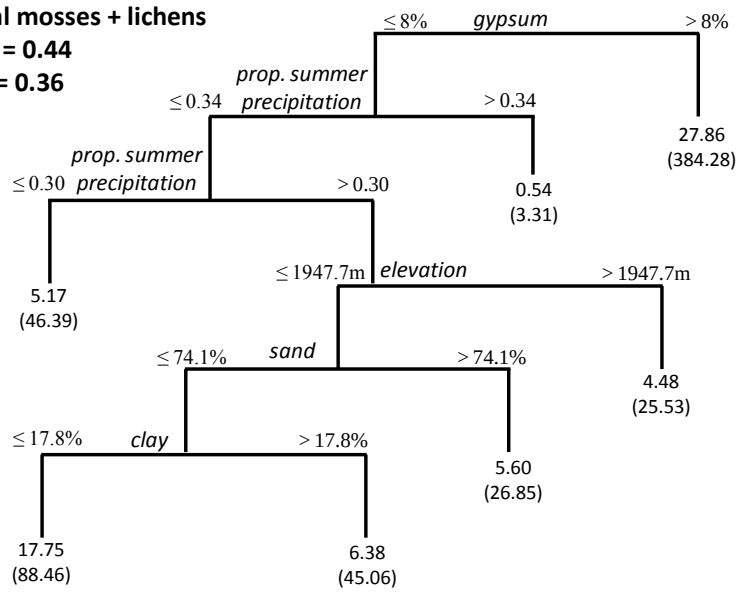
Figure 1. Primary regression tree models produced for the BLM Colorado Plateau REA. Models are read from top to bottom like a decision tree. Italicized text and associated values indicate split criteria. Predicted mean and variance of the response variable are presented at end nodes.



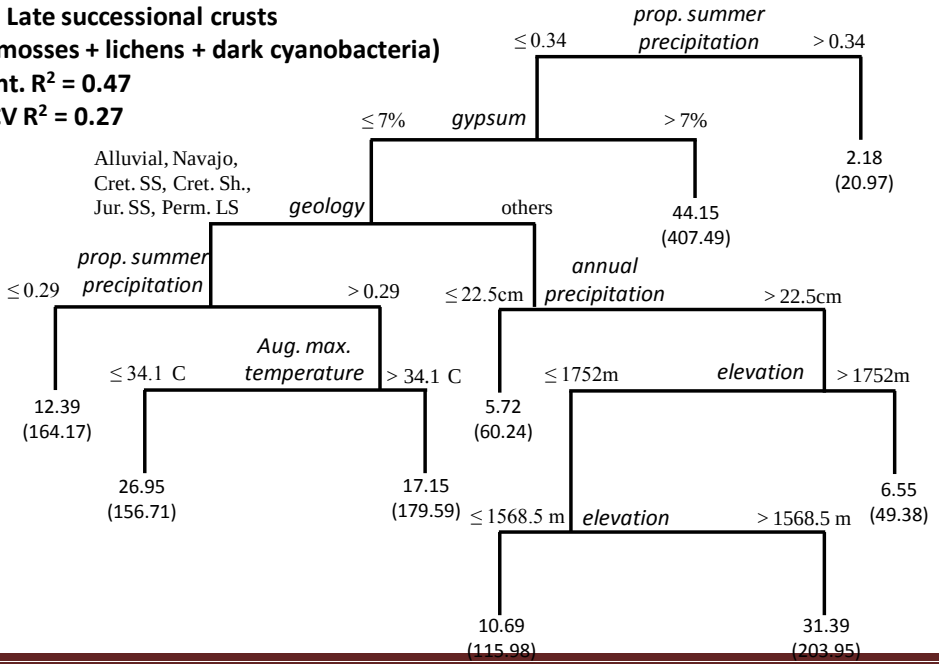
d. Total Lichen
Int. R^2 = 0.36
CV R^2 = 0.28

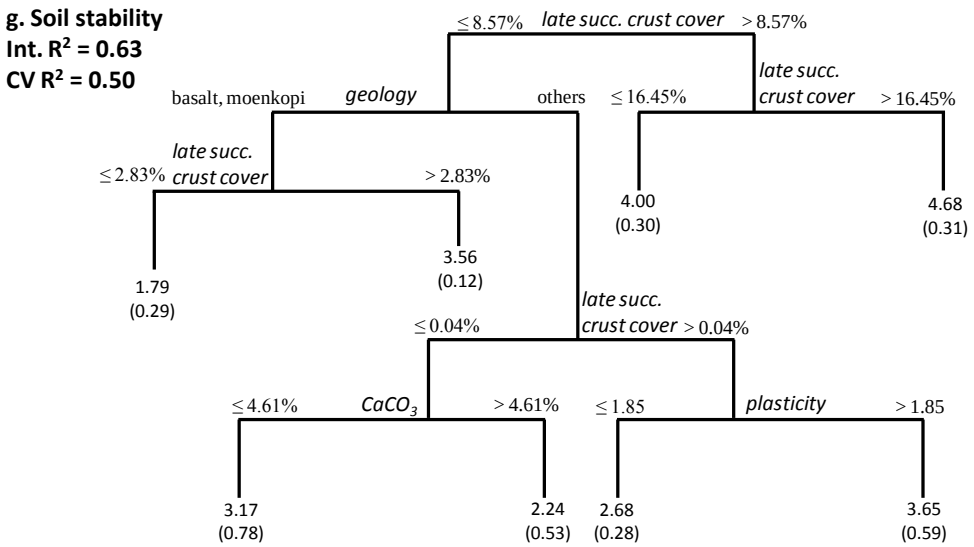


e. Total mosses + lichens
Int. R^2 = 0.44
CV R^2 = 0.36



f. Late successional crusts
(mosses + lichens + dark cyanobacteria)
Int. R^2 = 0.47
CV R^2 = 0.27





References Cited

Bowker, M.A., J. Belnap, D.W. Davidson, and S.L. Phillips. 2005. Evidence for micronutrient limitation of biological soil crusts: Importance to arid-lands restoration. *Ecological Applications* 15:1941–1951.

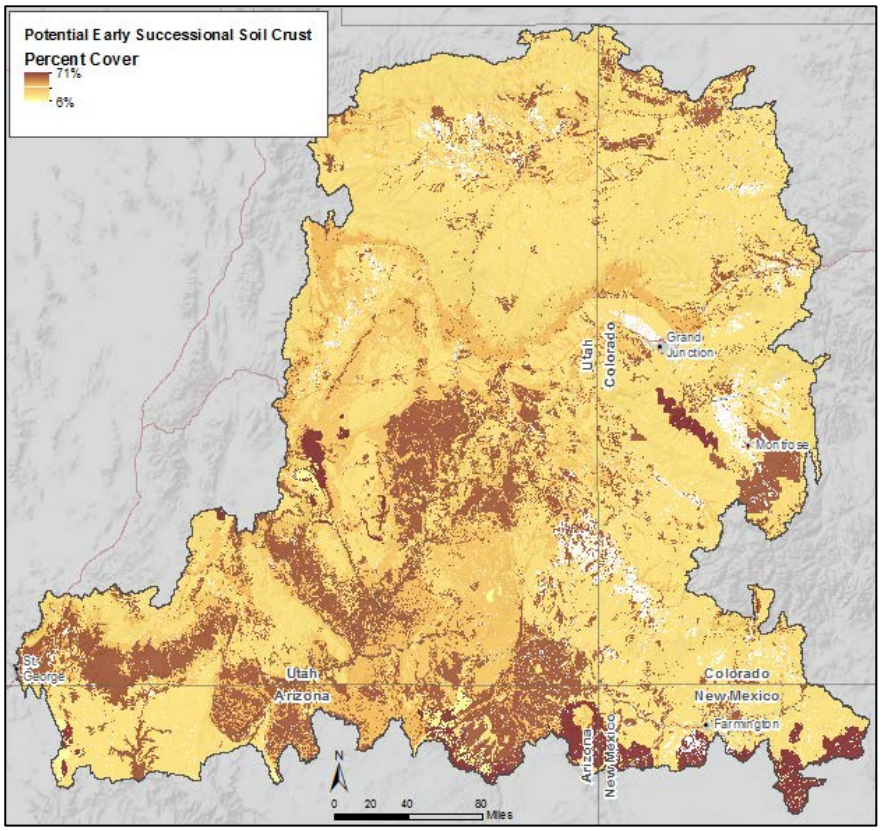
Bowker, M.A., and J. Belnap. 2007. Spatial modeling of biological soil crusts to support land management decisions: Indicators of range health and conservation and restoration value based upon the potential distribution of biological soil crusts in Montezuma Castle, Tuzigoot, Walnut Canyon, and Wupatki National Monuments, Arizona.

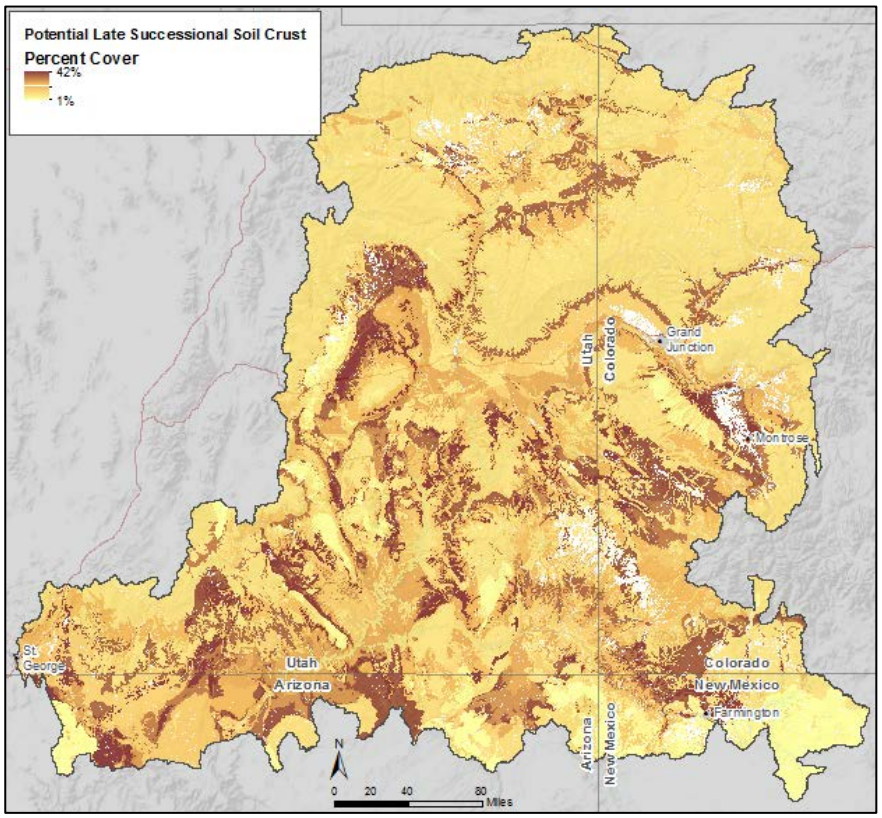
Bowker, M.A., J. Belnap, M.E. Miller. 2006. Spatial modeling of biological soil crusts to support rangeland assessment and monitoring. Rangeland Ecology and Management 59: 519-529

Burnham, K.P., and D.R. Anderson. 2002. Model selection and multi-model inference: A practical information-theoretic approach. Springer, New York.

Elith, J., J.K. Leathwick, T. Hastie. 2008. A working guide to boosted regression trees. *Journal of Animal Ecology* 77: 802–813.

Results: Modeled Early and Late Successional Biological Soil Crust



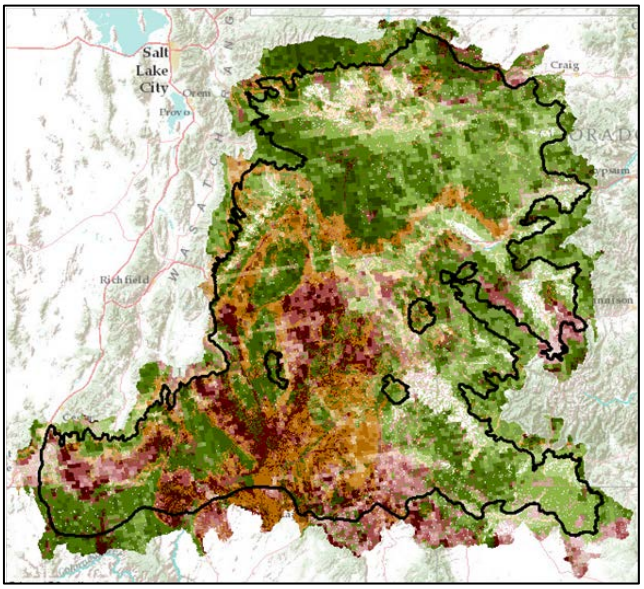


A. Soils, Biological Crust, and Forage Management
MQ A5. What/where is the potential for future change to the cryptogamic crusts?

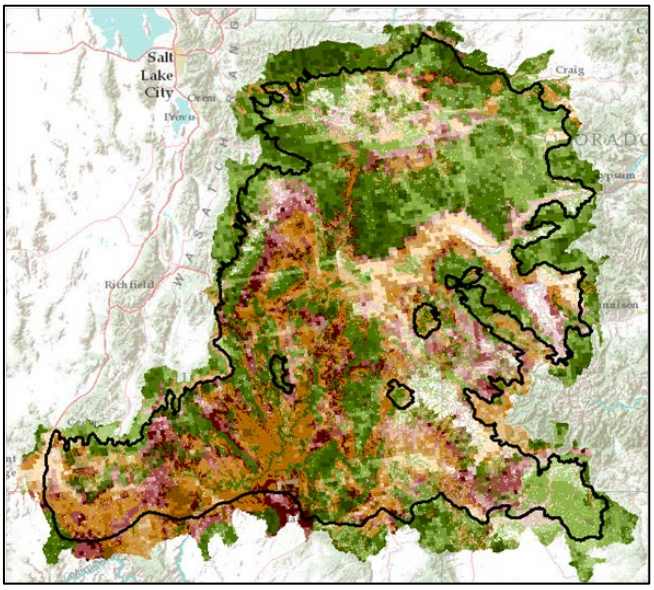
Process Model or Description

For each type of crust (early and late successional), we combined 3 natural breaks classes of soil crust (MQA4) with combined results of current and near-term terrestrial intactness and long-term potential for climate change and energy development. For potential for future change, we selected the highest category of potential crust based on natural breaks of the original data by Bowker and analyzed it against near-term intactness, potential energy, and climate change.

Results

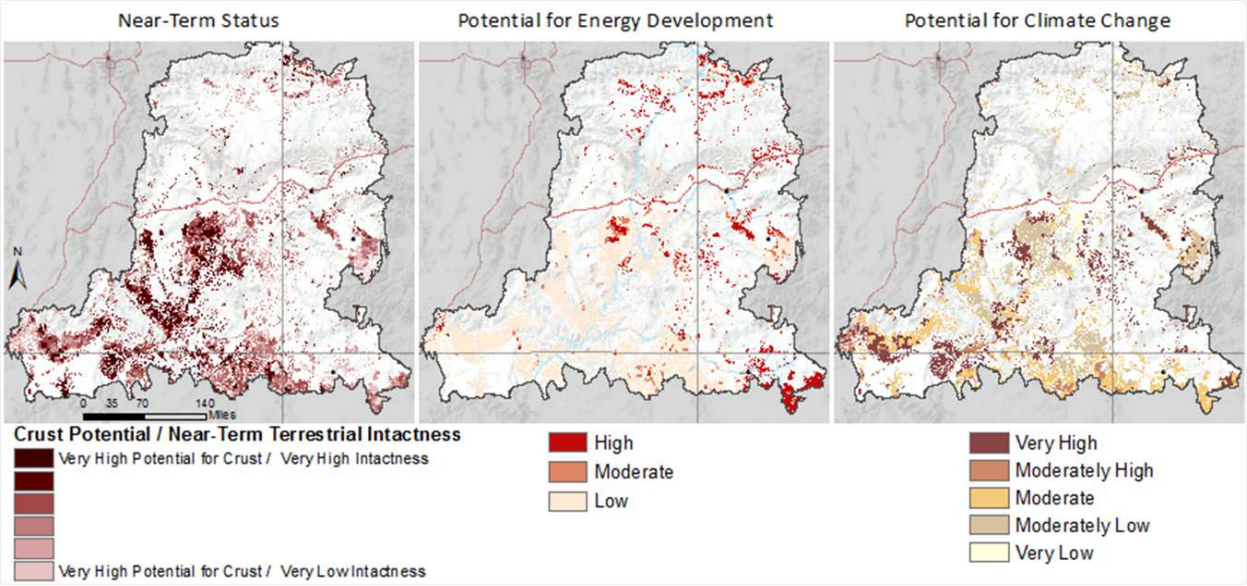


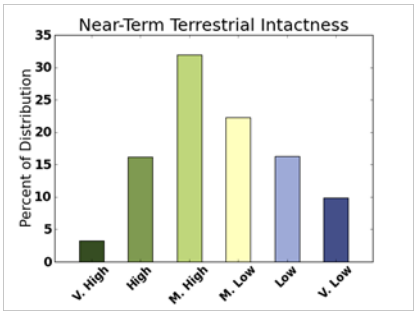
Early successional crust

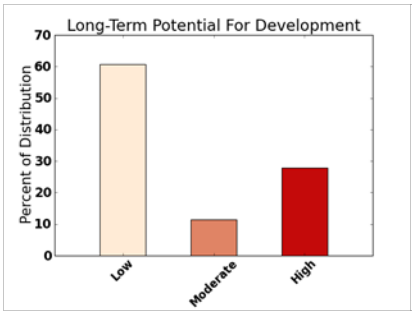


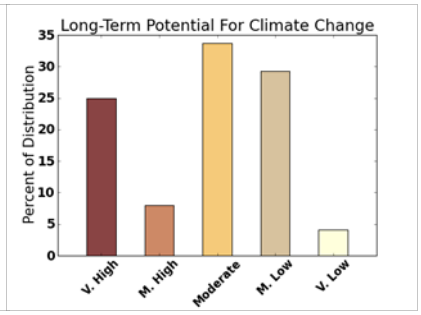
Late Successional Crust

Early Successional Crust

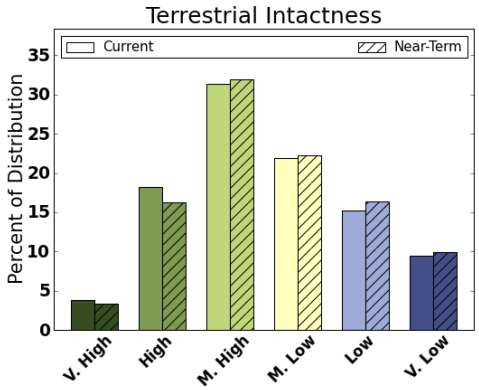






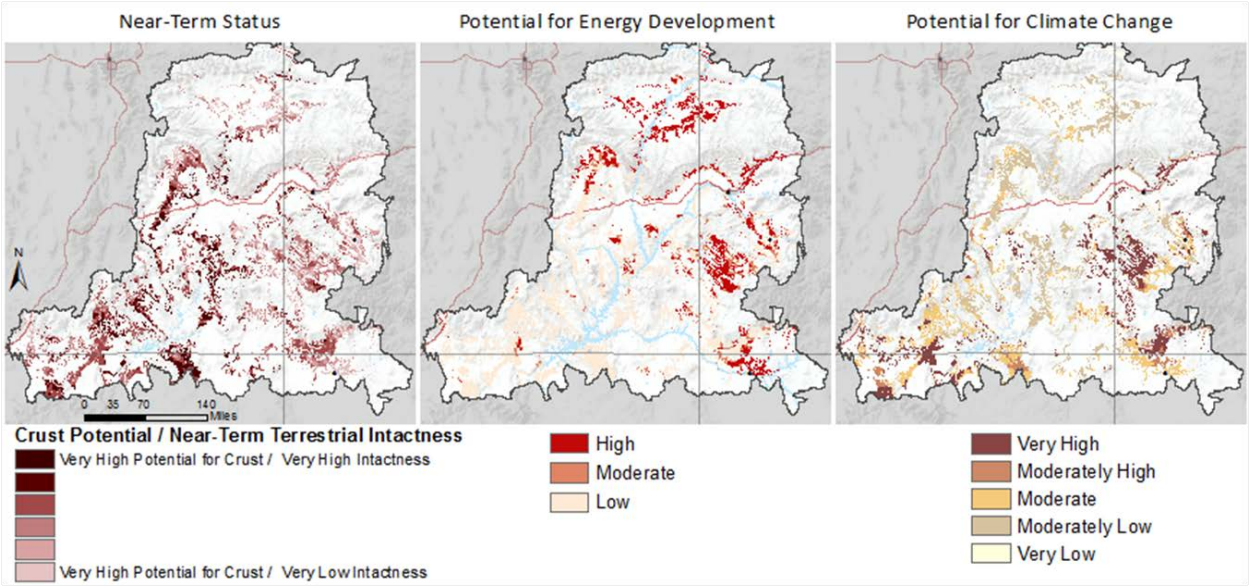


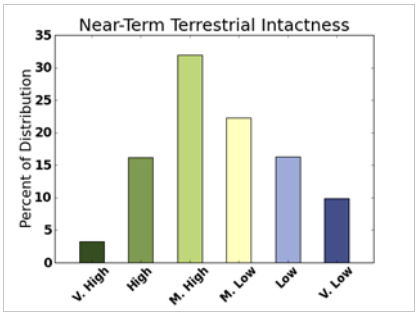
Current & Near-term Intactness

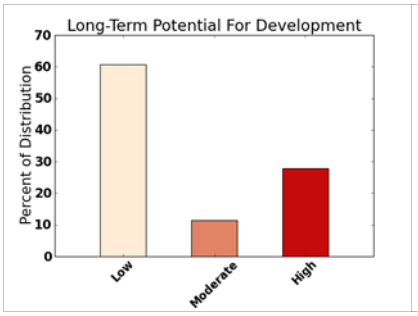


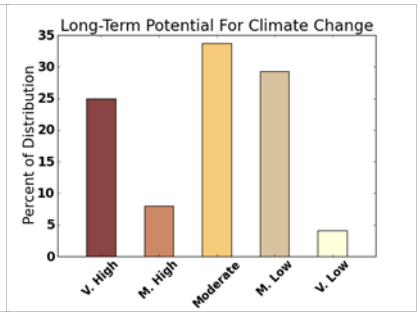
Current (solid color) and Near-term (cross-hatched) Intactness

Late Successional Crust

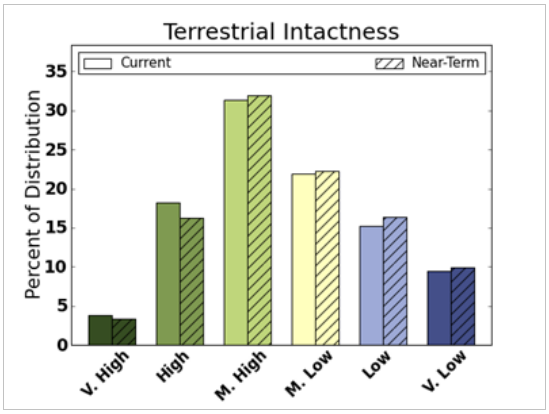








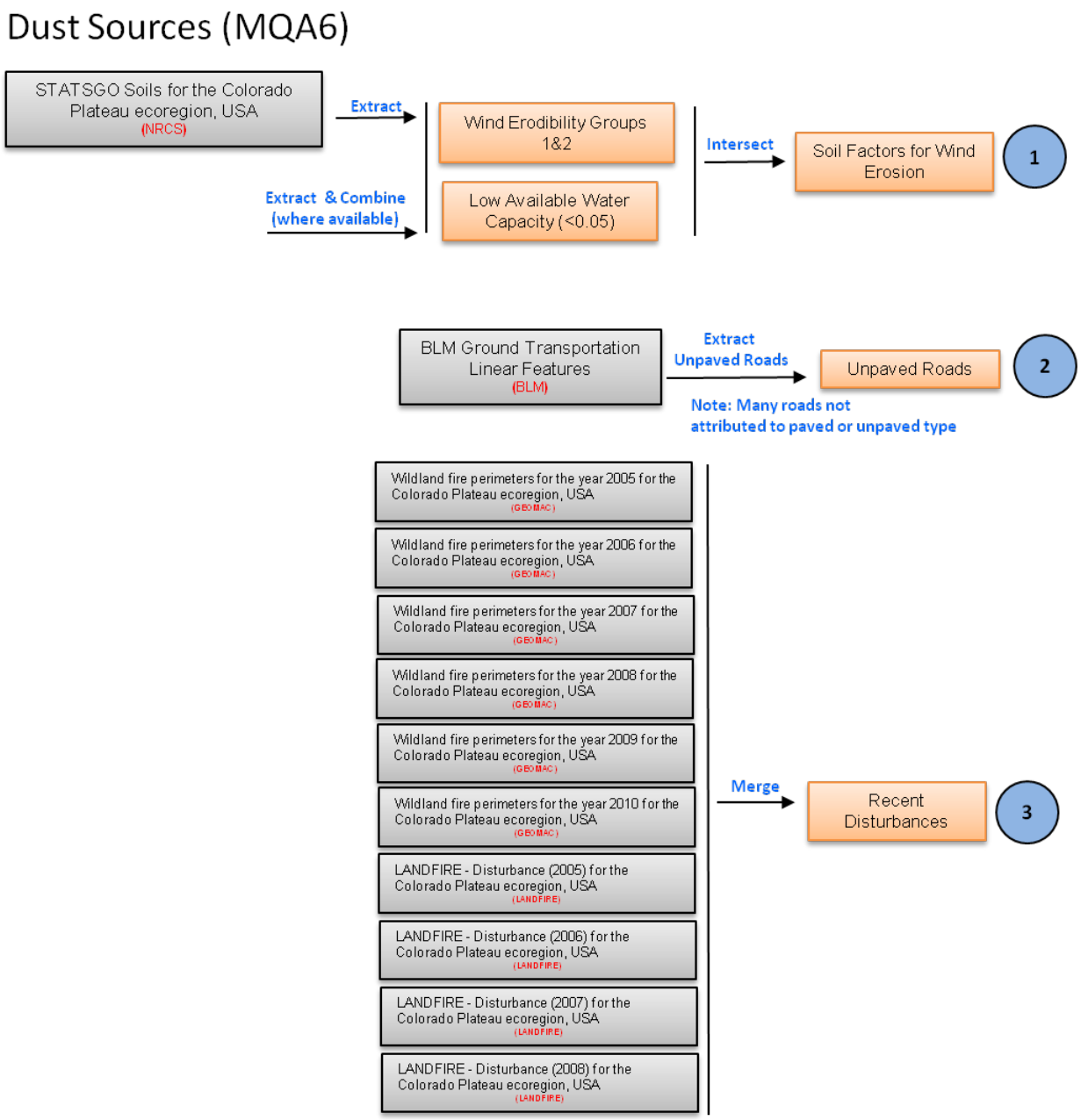
Current & Near-term Intactness

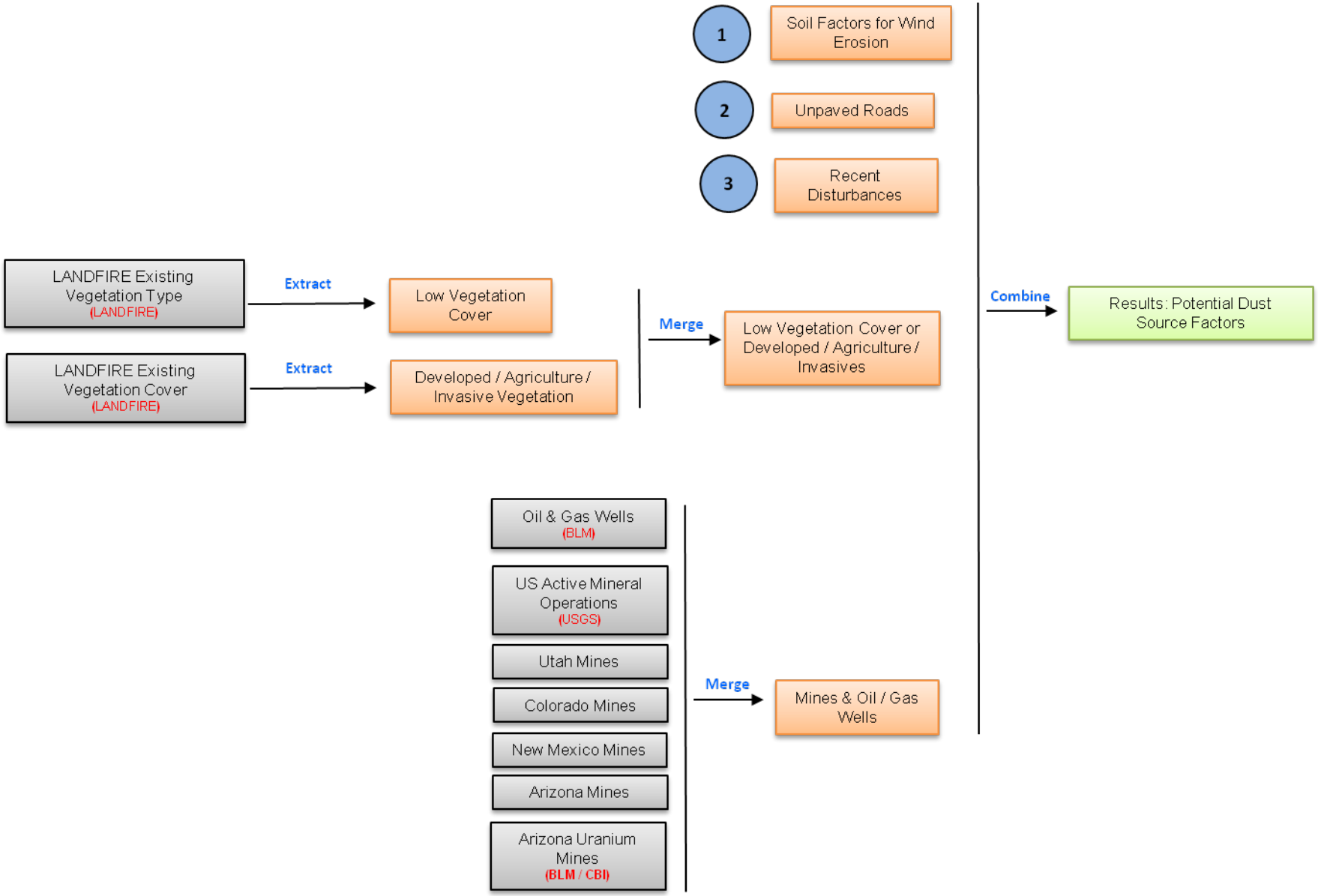


Current (solid color) and Near-term (cross-hatched) Intactness

A. Soils, Biological Crust, and Forage
MQ A6. Where are hotspots producing fugitive dust that may contribute to accelerated snow melt in the Colorado Plateau?

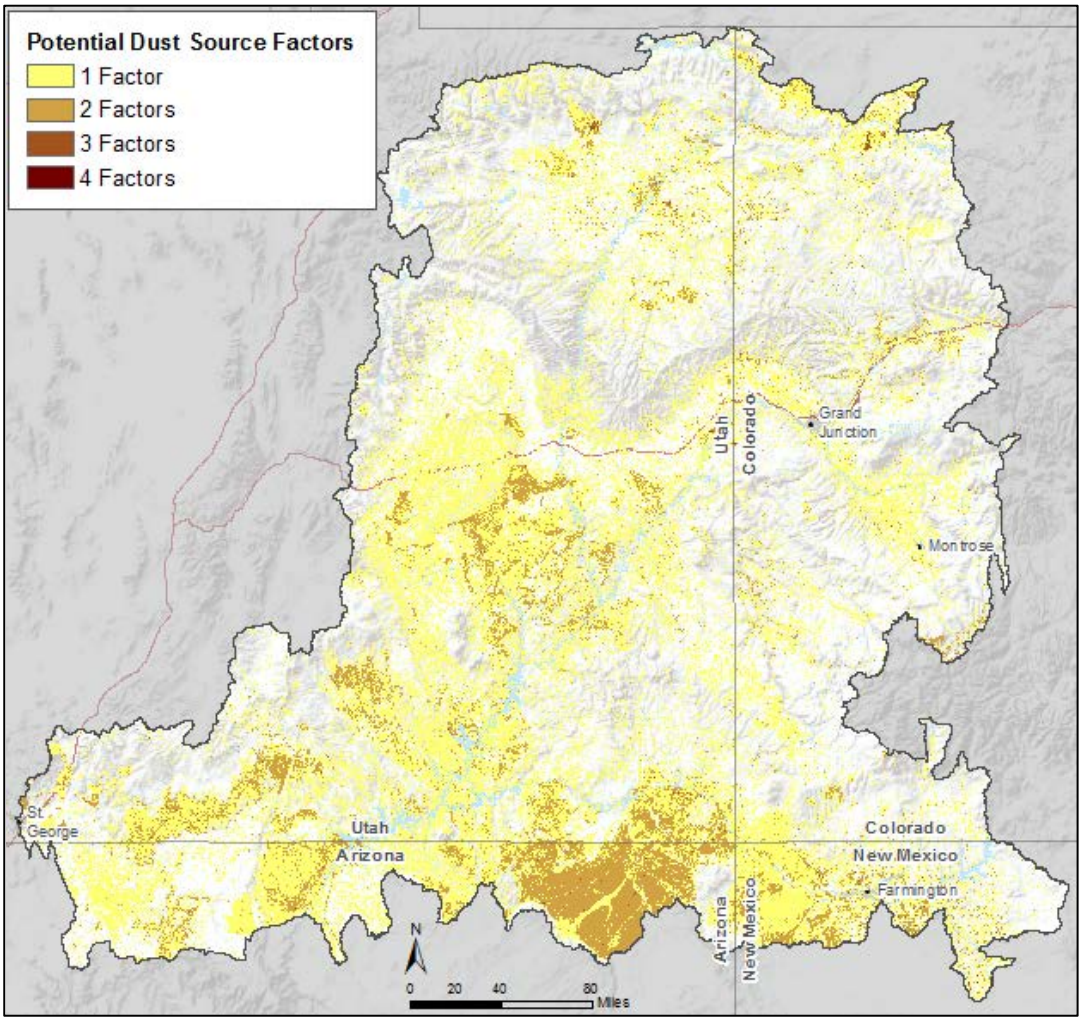
Process Model or Description




1
Soil Factors for Wind Erosion
2
Unpaved Roads
3
Recent Disturbances
LANDFIRE Existing Vegetation Type (LANDFIRE)
Extract
Low Vegetation Cover
LANDFIRE Existing Vegetation Cover (LANDFIRE)
Extract
Developed / Agriculture / Invasive Vegetation
Merge
Low Vegetation Cover or Developed / Agriculture / Invasives
Combine
Results: Potential Dust Source Factors
Oil & Gas Wells (BLM)
US Active Mineral Operations (USGS)
Utah Mines
Colorado Mines
New Mexico Mines
Arizona Mines
Arizona Uranium Mines (BLM / CBI)
Merge
Mines & Oil / Gas Wells

Results

MQ A6. Where are hotspots producing fugitive dust that may contribute to accelerated snow melt in the Colorado Plateau?



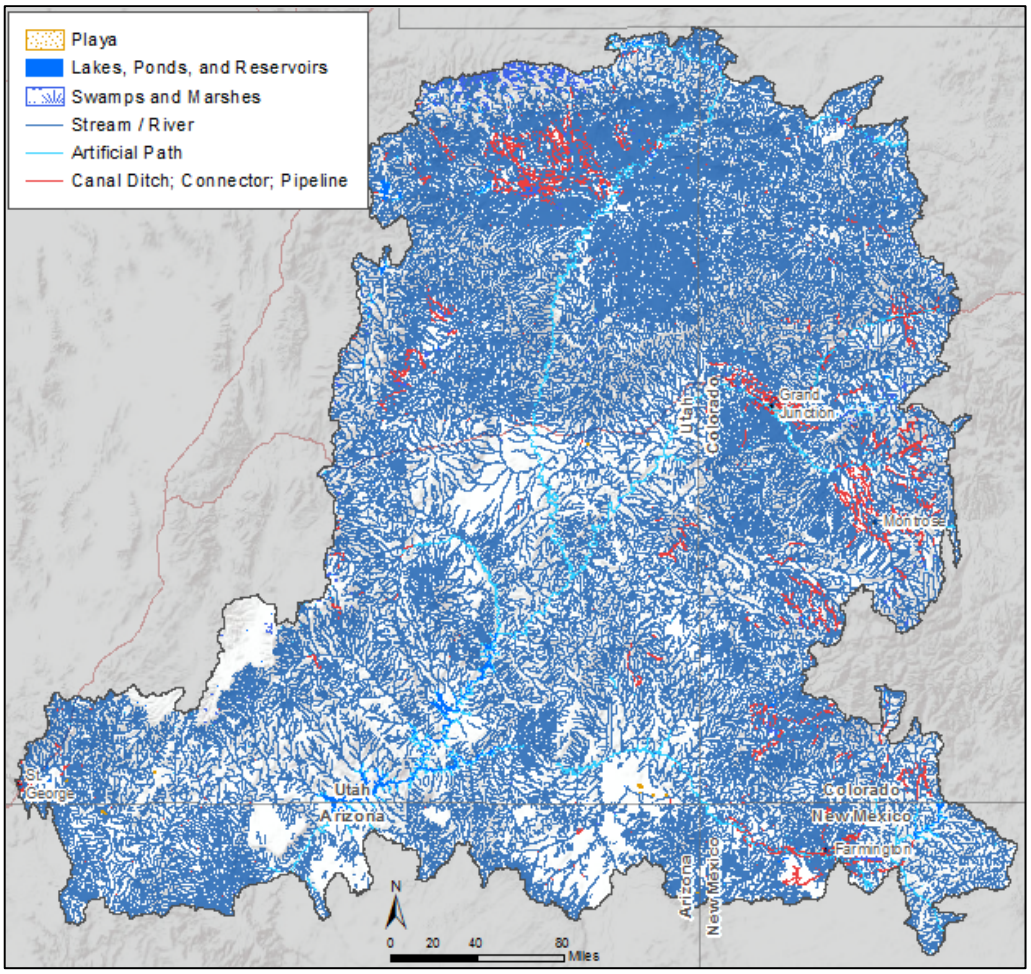
This dataset shows a number of factors that may contribute to dust production at a location. These factors include areas around mines and oil/gas wells, low vegetation cover or invasive annual vegetation, recent disturbances (since 2005), unpaved roads, and soils with high potential for wind erosion. Note that the roads factor should be treated with the least certainty because the dataset used for this analysis does not fully distinguish paved from unpaved roads. The combination of factors at a location may produce a non-linear response with respect to dust production: each factor alone may have varying magnitude depending on location, local wind and topography, and degree of disturbance. Factors may combine such that the net effect is greater than the sum of the factors taken independently

B. Surface and Groundwater
MQ B1. Where are lotic and lentic surface waterbodies and livestock and wildlife watering tanks and artificial water bodies?

Process Model or Description

Features from National Hydrography Dataset (USGS) Flowlines and Water Bodies datasets extracted.
Flowlines represent ephemeral, intermittent, and perennial stream channels.

Results

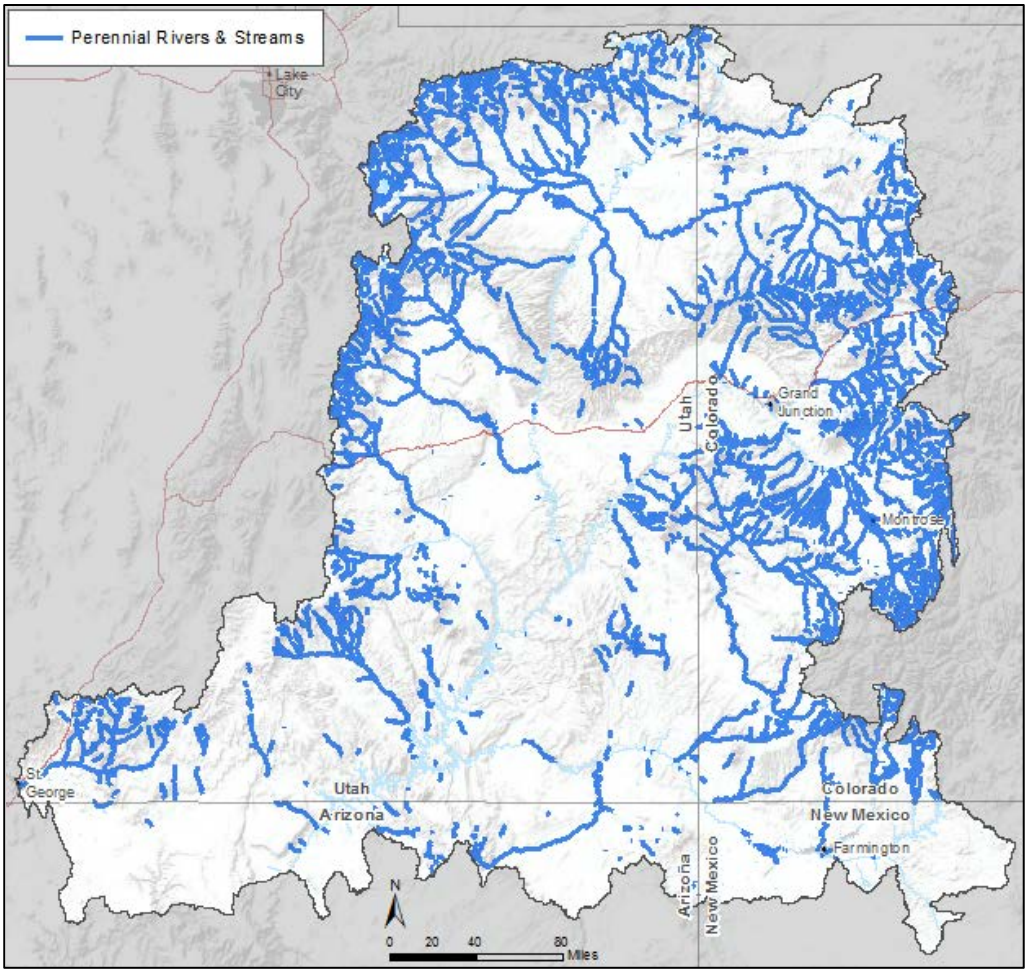


B. Surface and Groundwater
MQ B2. Where are perennial streams and stream reaches?

Process Model or Description

Features marked as perennial streams from National Hydrography Dataset (USGS) Flowlines (note: many features that may in fact be perennial were not marked as such, due to use of other labels, e.g., Artificial Path)

Results



B. Surface and Groundwater
MQ B3. What are seasonal discharge maxima and minima for the Colorado River and major tributaries at gaging stations?

Process Description

For each gaging station, daily summary statistics were obtained from USGS for the period of record of the station up to 9/30/2010. Daily statistics were partitioned into seasons and minimums and maximums calculated for each season.

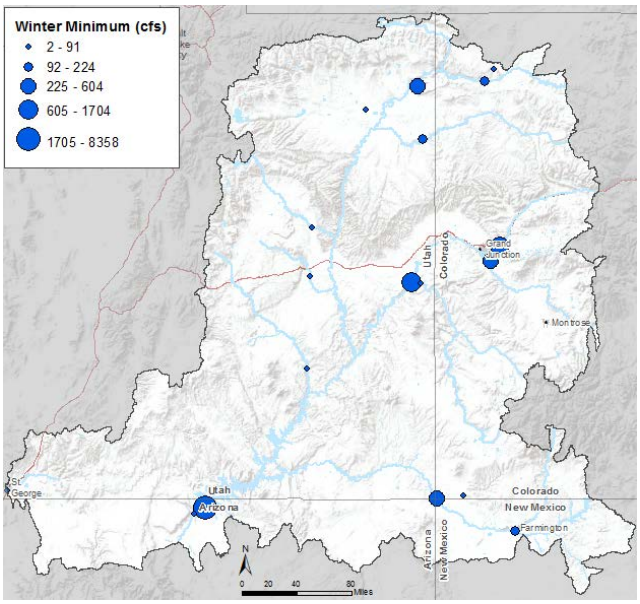
Table 4.2. Average seasonal maxima and minima for gaging stations on the Colorado River and major tributaries recording 7–102 years of records from various stations through 9-30-2010 (Source weblink: http://waterdata.usgs.gov/nwis. Figures in cubic feet/second (cfs) rounded to the nearest cfs.

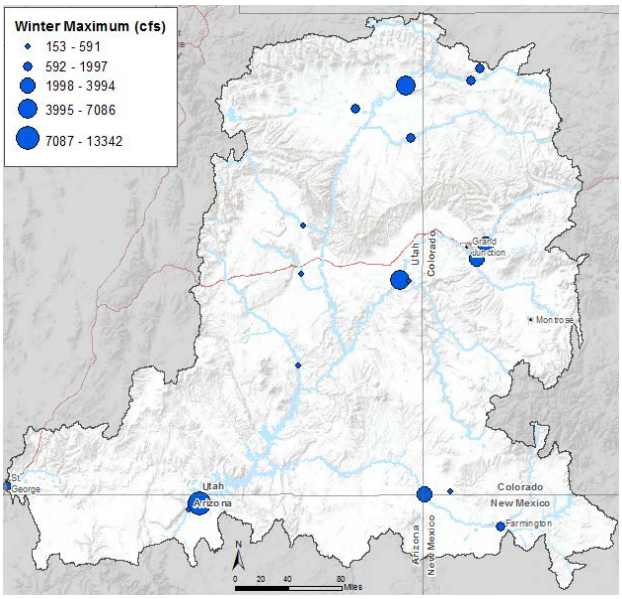
Gaging Station Location	SPMN	SPMX	SUMN	SUMX	FMN	FMX	WMN	WMX
GREEN RIVER NEAR JENSEN, UT	2481	23991	559	11378	430	5089	604	6220
YAMPA RIVER AT DEERLODGE PARK, CO.	1670	15381	56	4485	161	1392	224	1643
DUCHESNE RIVER NEAR RANDLETT, UT	19	4570	7	2930	31	1560	47	1264
WHITE RIVER NEAR WATSON, UTAH	301	3581	79	2886	207	1135	190	1280
PRICE RIVER AT WOODSIDE, UT	8	1646	1	1299	11	731	13	271
COLO RIVER NR PALISADE CO	945	13246	161	9551	839	2621	1130	2500
SAN RAFAEL RIVER NEAR GREEN RIVER, UT	4	1768	0	1391	3	885	11	449
GUNNISON RIVER GRAND JUNCTION, CO.	541	18088	174	9474	361	3671	498	3859
COLORADO RIVER NEAR CISCO, UT	2041	43002	991	25958	1565	9093	1704	7086
DOLORES RIVER NEAR CISCO, UT	110	6132	16	1617	94	895	91	591
DIRTY DEVIL R NR HANKSVILLE, UT	9	562	0	1218	21	1434	36	342
VIRGIN RIVER NEAR BLOOMINGTON, UT	25	1938	10	644	42	722	56	1997
PARIA RIVER AT LEES FERRY, AZ	3	165	2	939	5	502	6	354
SAN JUAN RIVER AT FOUR CORNERS, CO	536	9613	283	6978	518	3853	537	3994
MANCOS RIVER NEAR TOWAOC, CO.	0	700	0	465	0	264	2	153
ANIMAS RIVER AT FARMINGTON, NM	124	5806	8	4292	108	2042	142	861

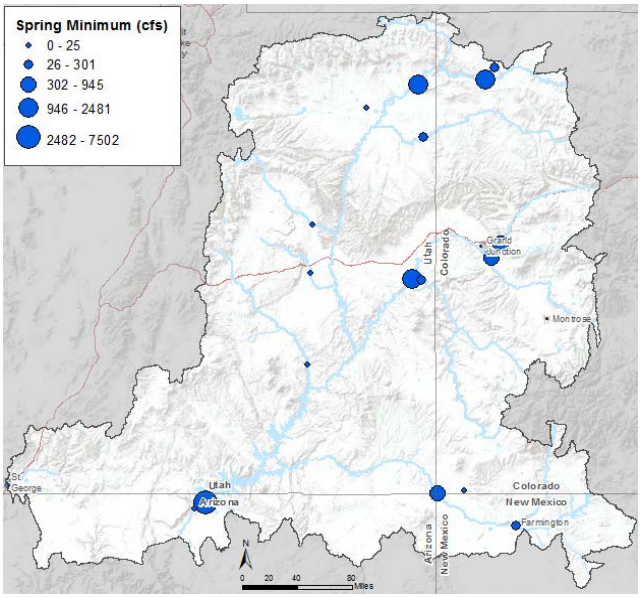
SPMN=spring minimum; SPMX=spring maximum; SUMN=summer minimum; SUMX=summer maximum; FMN=fall minimum; FMX=fall maximum; WMN=winter minimum; WMX=winter maximum.

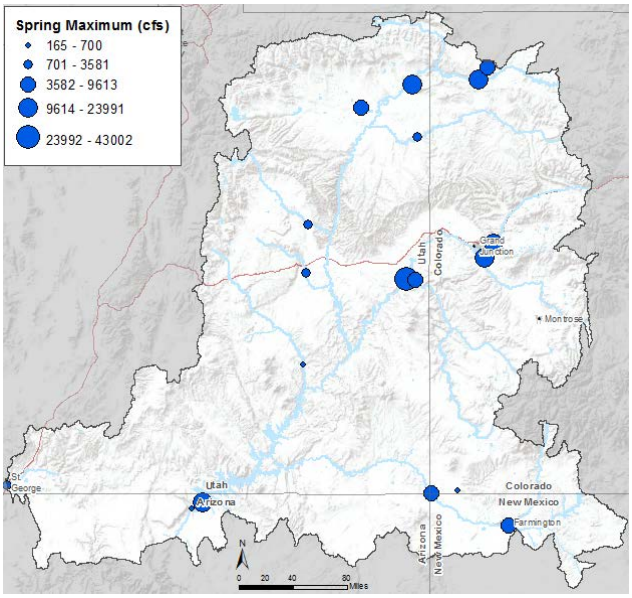
MQ B3. What are seasonal discharge maxima and minima for the Colorado River and major tributaries at gaging stations?

Results for Seasonal Max/Min at Various Gaging Stations: Winter/Spring



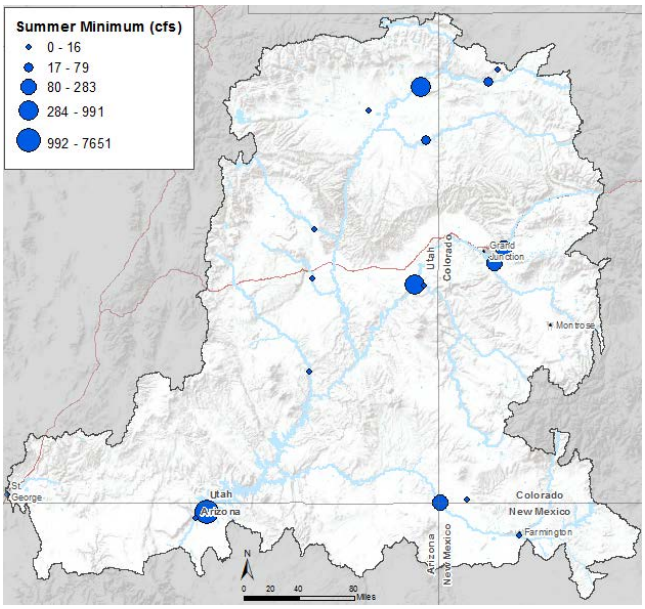


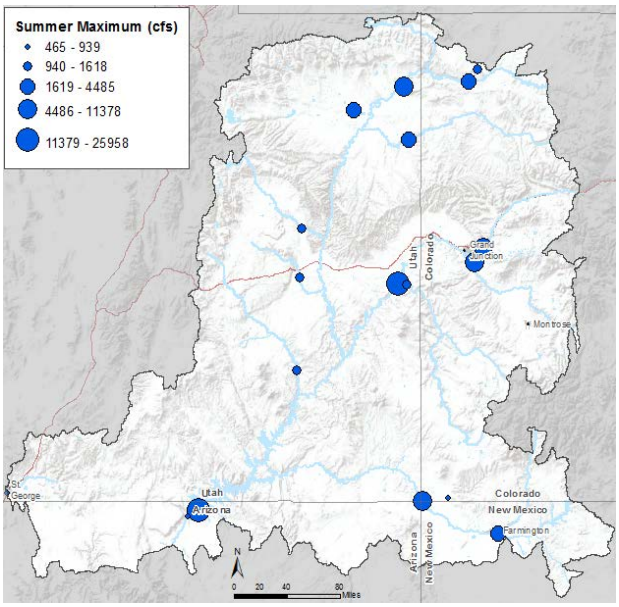


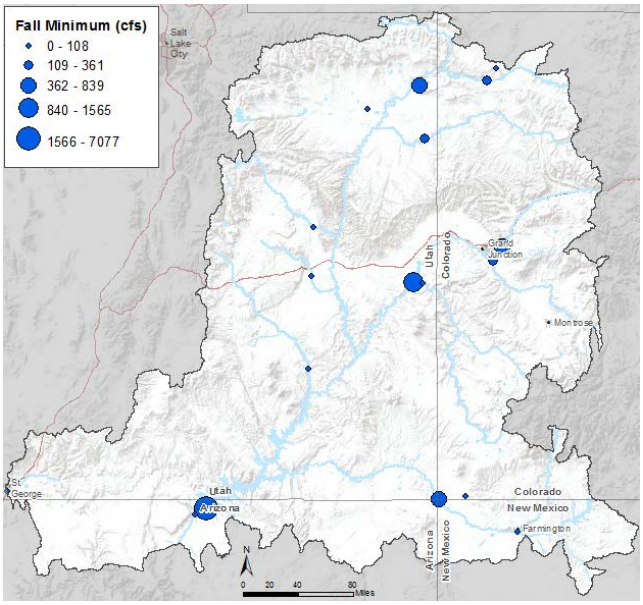


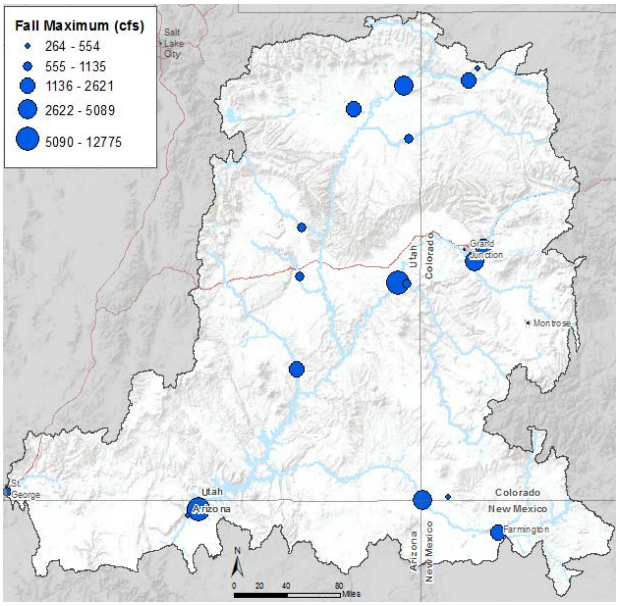
MQ B3. What are seasonal discharge maxima and minima for the Colorado River and major tributaries at gaging stations?

Results for Seasonal Max/Min at Various Gaging Stations: Summer/Fall







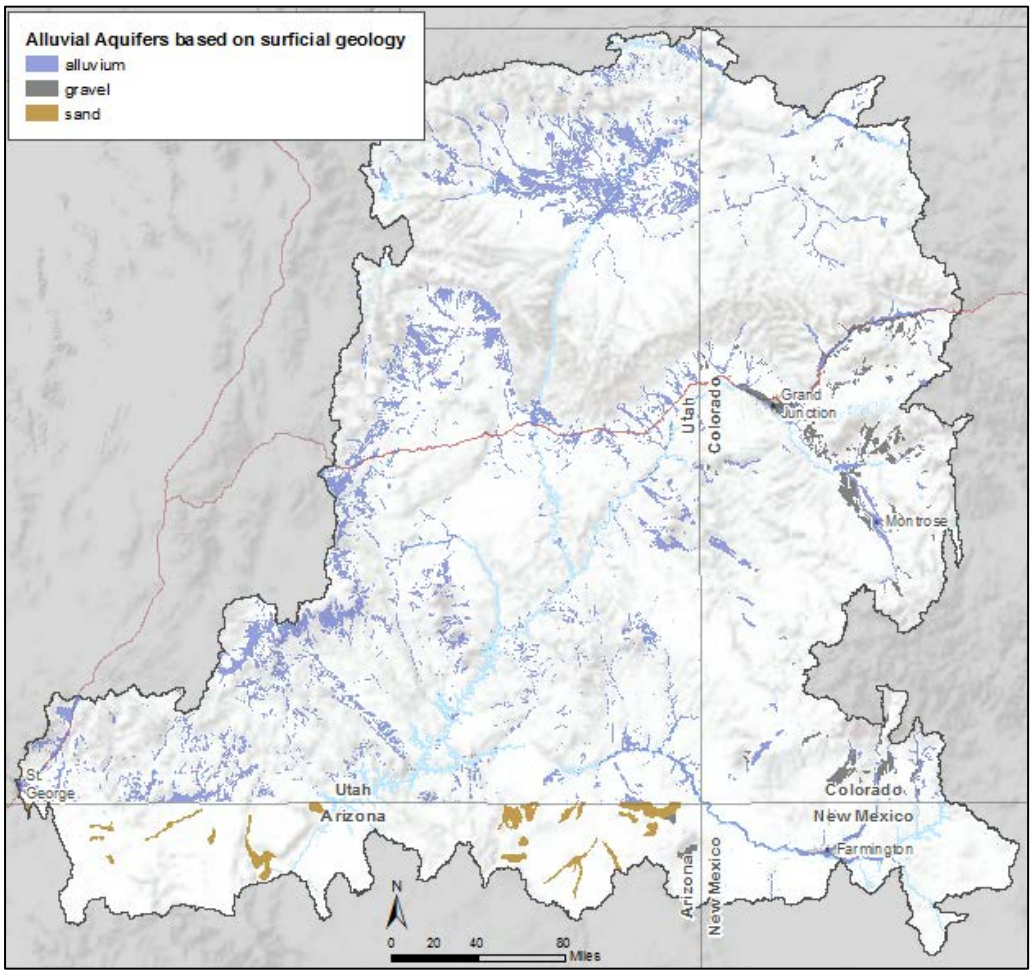


B. Surface and Groundwater
MQ B4. Where are the alluvial aquifers and their recharge areas (if known)?

Process Model or Description

Alluvium, sand, and gravel types were selected from composite state geology dataset.

Results for Alluvial Aquifers

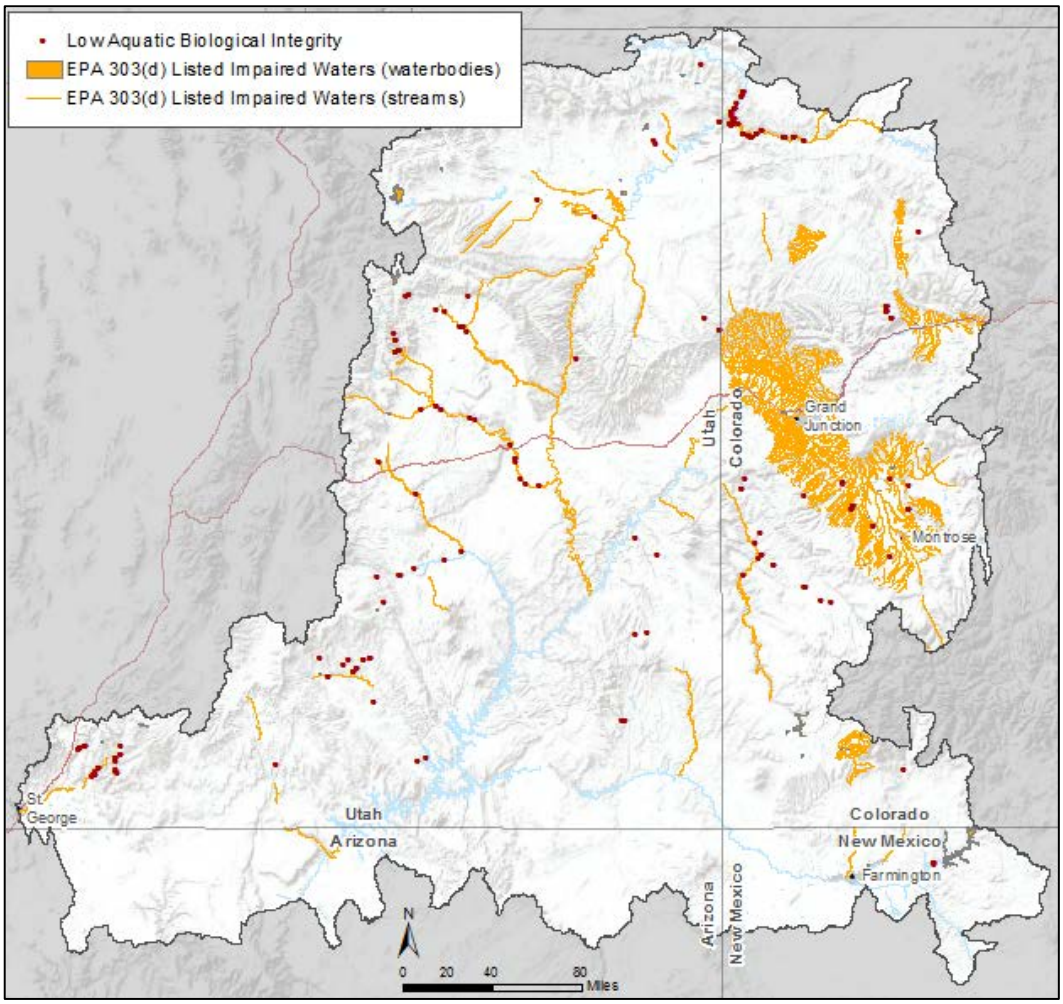


B. Surface and Groundwater
MQ B6. Where are the aquatic systems listed in 303(d) with degraded water quality or low macroinvertebrate diversity?

Process Model or Description

Features were identified in Environmental Protection Agency (EPA) 303(d) datasets. Explanation of 303(d) below from EPA website http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/overview.cfm : The term "303(d) list" refers to the list of impaired and threatened waters (stream and river segments, lakes) that the Clean Water Act requires all states to submit for EPA approval every two years on even-numbered years. The states identify all waters where required pollution controls are not sufficient to attain or maintain applicable water quality standards, and establish priorities for development of Total Maximum Daily Loads (TMDLs) based on the severity of the pollution and the sensitivity of the uses to be made of the waters, among other factors. States then provide a long-term plan for completing TMDLs within 8 to 13 years from first listing.

Results for 303(d) waters and Sites with Low Macroinvertebrate Scores



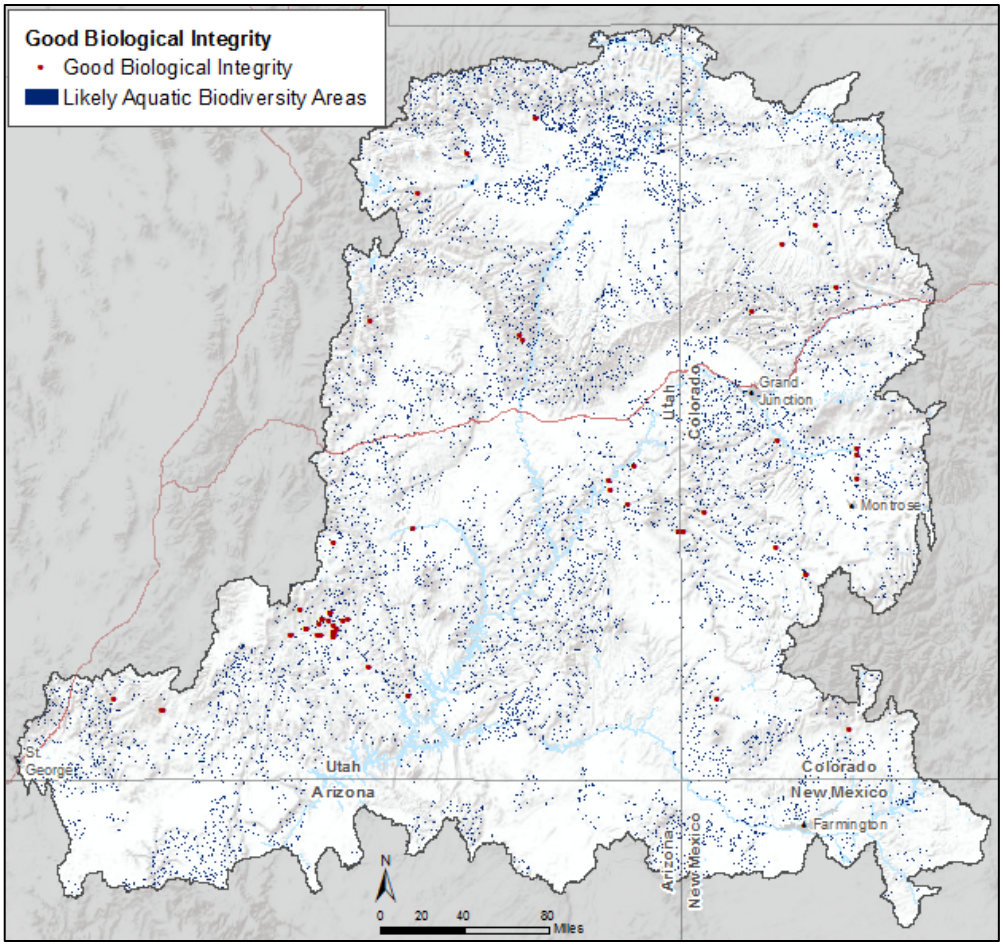
B. Surface and Groundwater
MQ B7. What is the location/distribution of these aquatic biodiversity sites?

Process Model or Description

40 meter buffers were selected around NHD flowlines, wetlands, and deep water habitats (USFWS) that fell within Nature Conservancy (TNC) Conservation Portfolio areas or Special Designations.

Biological integrity was assessed using an observed/expected (O/E) index. O/E models compare the macroinvertebrate taxa observed at sites of unknown biological condition (i.e., 'test sites') to the assemblages expected to be found in the absence of anthropogenic stressors. Test sites scoring less than one SD below the mean of reference sites (mean OE =1.01, standard deviation = 0.17) are considered in "Good" biological condition. Sites scoring more than two SD below the mean of reference sites are considered in "Poor" biological condition (see previous map for MQ B6).

Results for Aquatic Biodiversity Areas and Sites with High Macroinvertebrate Scores



C. Ecological Systems Conservation Elements
Colorado Plateau Pinyon-Juniper Woodland – go to Appendix B
MQ C1. Where is existing Colorado Plateau Pinyon-Juniper Woodland and what is its status?
MQ C2. Where are vegetative communities vulnerable to change agents in the future?
MQ C3. What change agents have affected existing vegetative communities?
Colorado Plateau Pinyon-Juniper Shrubland - go to Appendix B
MQ C1. Where is existing Colorado Plateau Pinyon-Juniper Shrubland and what is its status?
MQ C2. Where are vegetative communities vulnerable to change agents in the future?
MQ C3. What change agents have affected existing vegetative communities?
Inter-Mountain Basins Big Sagebrush Shrubland - go to Appendix B
MQ C1. Where is existing Inter-mountain Basins Big Sagebrush Shrubland and what is its status?
MQ C2. Where are vegetative communities vulnerable to change agents in the future?
MQ C3. What change agents have affected existing vegetative communities?
Inter-Mountain Basins Montane Sagebrush Steppe - go to Appendix B
MQ C1. Where is existing Inter-Mountain Basins Montane Sagebrush Steppe and what is its status?
MQ C2. Where are vegetative communities vulnerable to change agents in the future?
MQ C3. What change agents have affected existing vegetative communities?
Rocky Mountain Gambel Oak-Mixed Montane Shrubland - go to Appendix B
MQ C1. Where is existing Rocky Mt. Gambel Oak-Mixed Montane Shrubland and what is its status?
MQ C2. Where are vegetative communities vulnerable to change agents in the future?
MQ C3. What change agents have affected existing vegetative communities?
Colorado Plateau Blackbrush-Mormon Tea Shrubland - go to Appendix B
MQ C1. Where is existing Colorado Plateau Blackbrush-Mormon Tea Shrubland and what's its status?
MQ C2. Where are vegetative communities vulnerable to change agents in the future?
MQ C3. What change agents have affected existing vegetative communities?
Inter-Mountain Basins Mixed Salt Desert Scrub - go to Appendix B
MQ C1. Where is existing Inter-mountain Basins Mixed Salt Desert Scrub and what is its status?
MQ C2. Where are vegetative communities vulnerable to change agents in the future?
MQ C3. What change agents have affected existing vegetative communities?
Colorado Plateau Mixed Bedrock Canyon and Tablelands - go to Appendix B
MQ C1. Where is Colorado Plateau Mixed Bedrock Canyon and Tablelands and what is its status?
MQ C2. Where are vegetative communities vulnerable to change agents in the future?
MQ C3. What change agents have affected existing vegetative communities?
Riparian Vegetation - go to Appendix B
MQ C1. Where is existing Riparian Vegetation and what is its status?
MQ C2. Where are vegetative communities vulnerable to change agents in the future?
MQ C3. What change agents have affected existing vegetative communities?

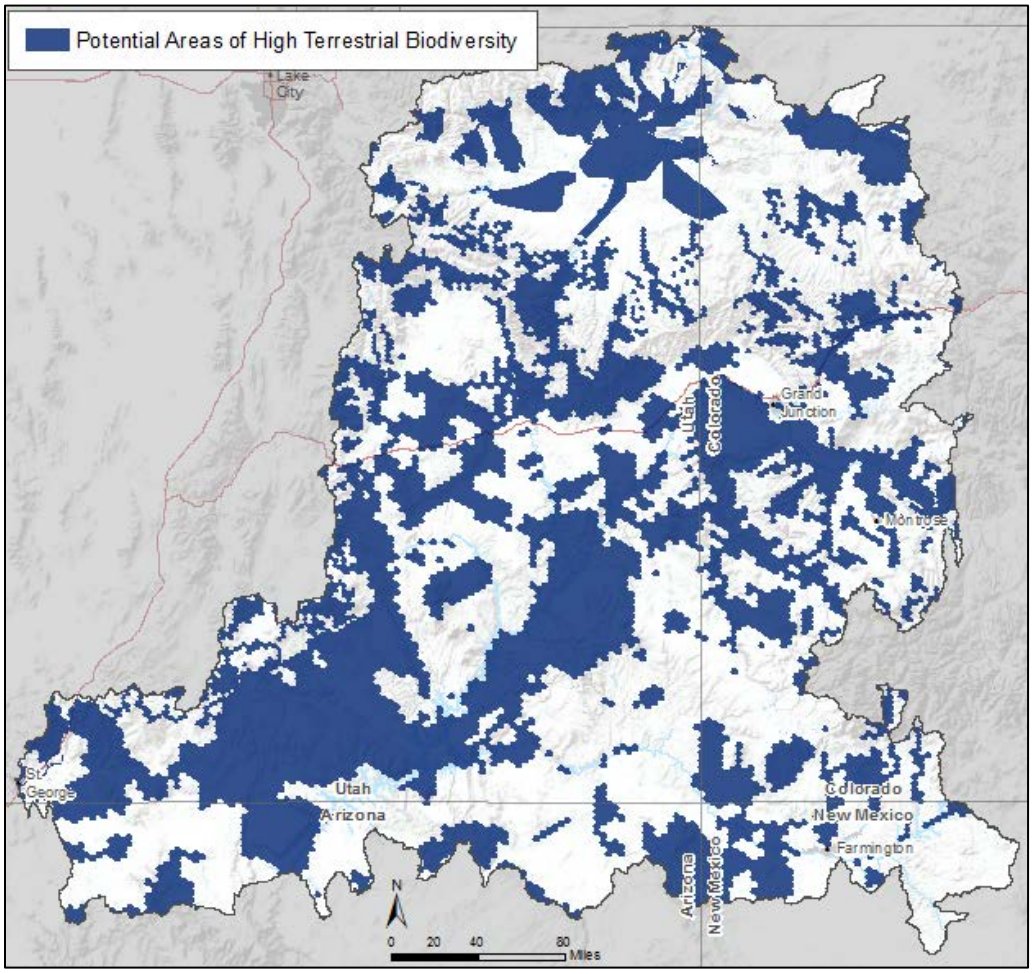
D. Species Conservation Elements
MQ D5. What is the location/distribution of terrestrial biodiversity sites and designated sites?

Process Model or Description

Terrestrial Biodiversity Sites are defined by TNC Terrestrial Conservation Portfolio areas plus Special Designations: combined CBI Protected Areas Database GAP 1 & 2, roadless areas (USFS), and conservation easements (NCED) with recent versions of wilderness areas and areas of critical environmental concern (BLM). Map also shows national historic and scenic trails, and wild and scenic rivers.

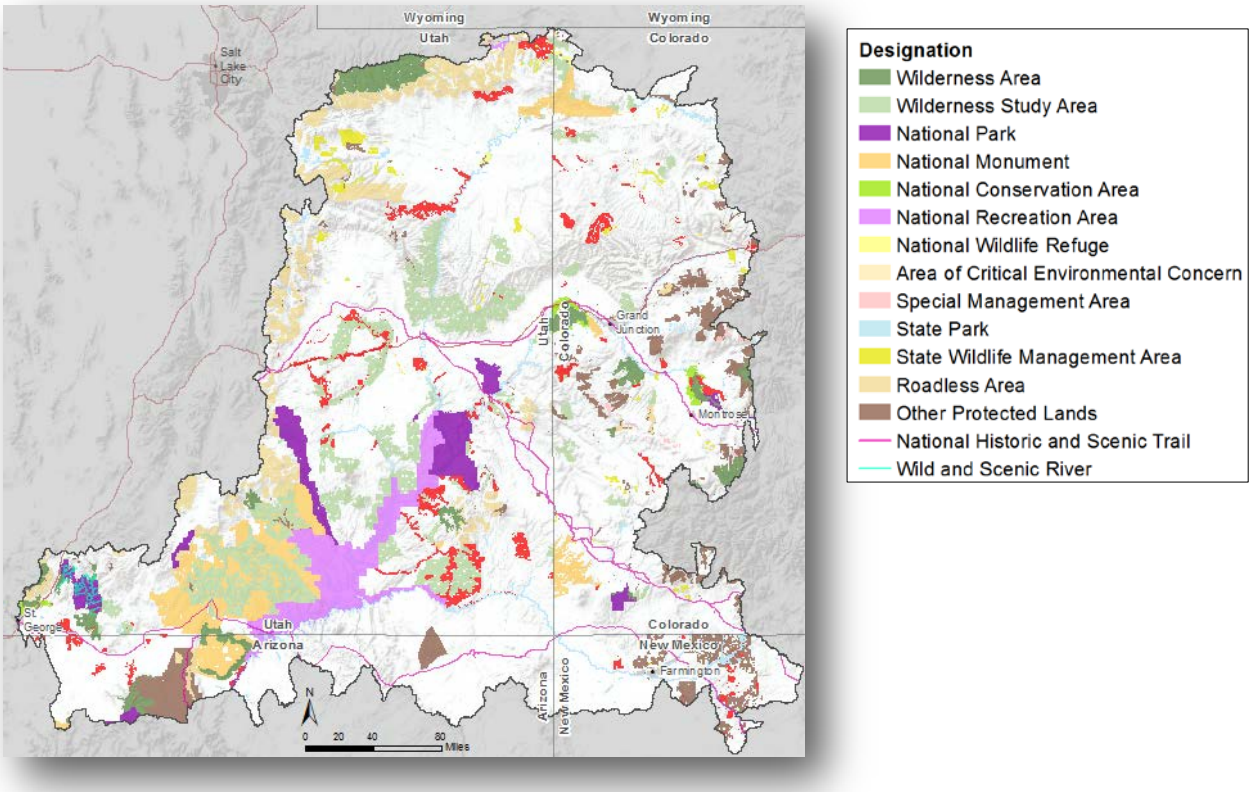
Results

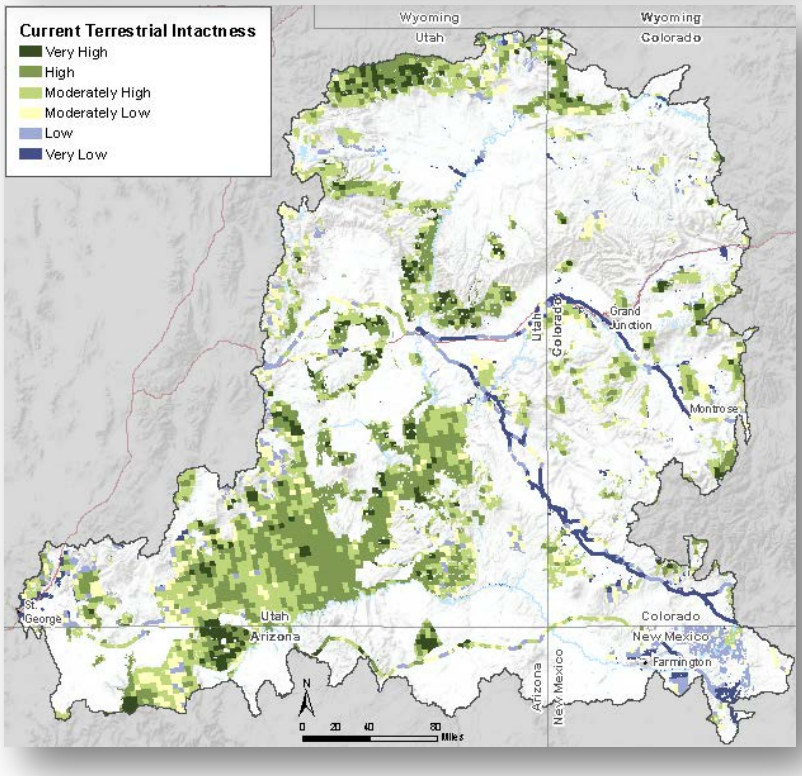
MQ D5. What is the location/distribution of terrestrial biodiversity sites?

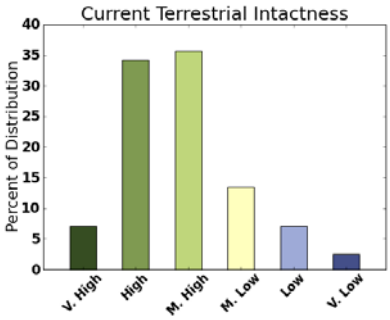


MQ D5. What is the location/distribution of designated sites?

Map of Designated Sites Distribution (Top) and Status of Designated Sites (Bottom)





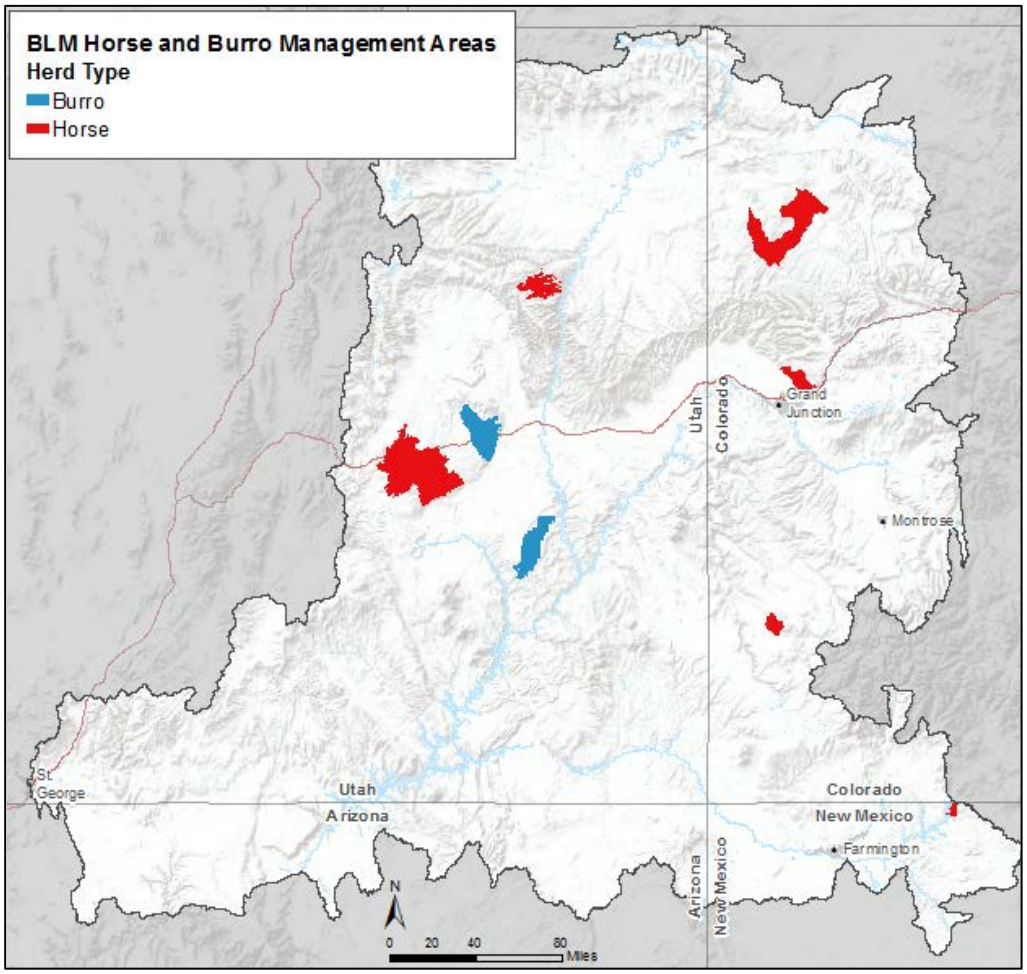


D. Species Conservation Elements
MQ D7. Where are HMAs located?

Process Model or Description

Data on BLM Wild Horse and Burro Herd Management Areas (HMAs) obtained from BLM.

Results for Wild Horse and Burro Herd Management Areas

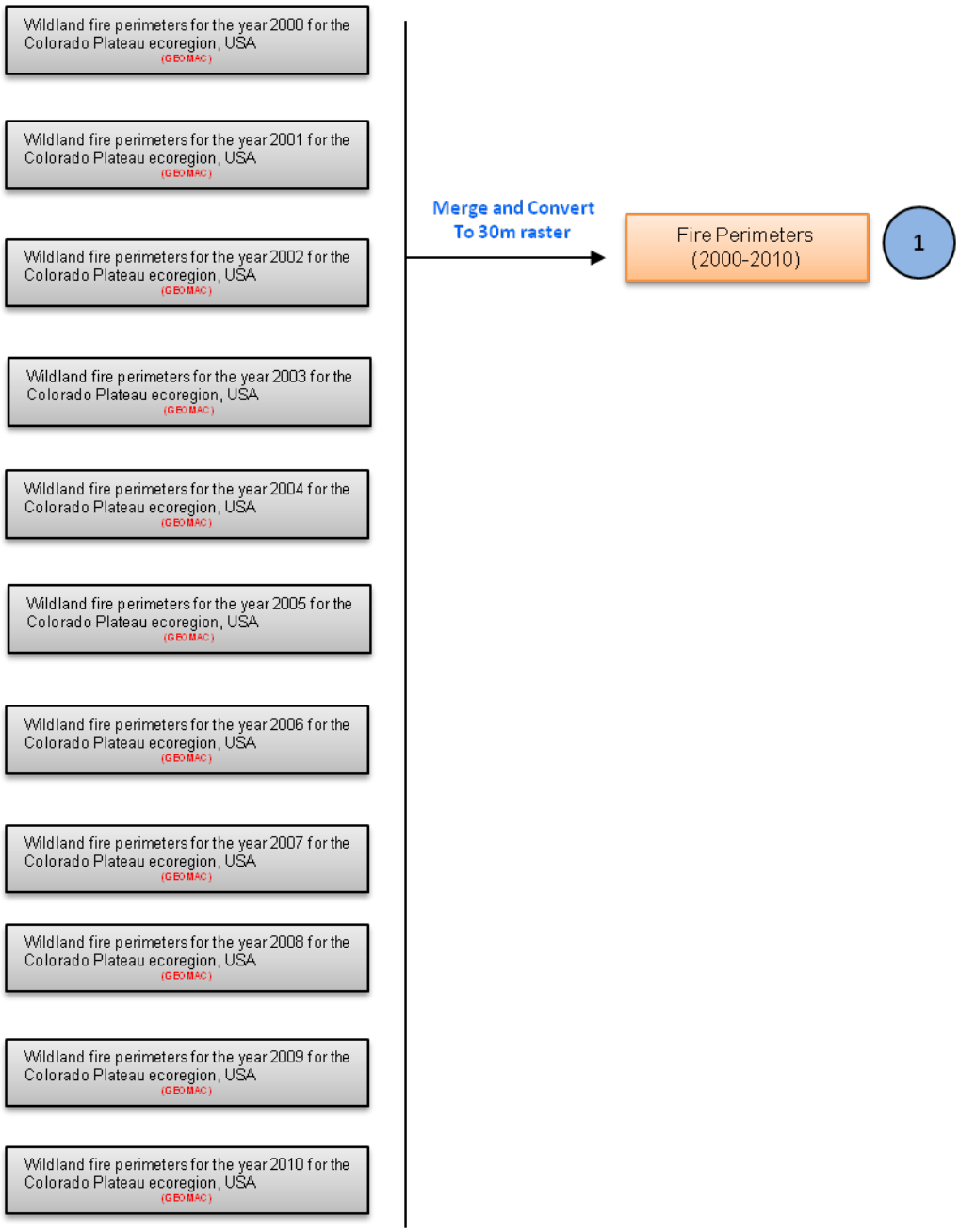


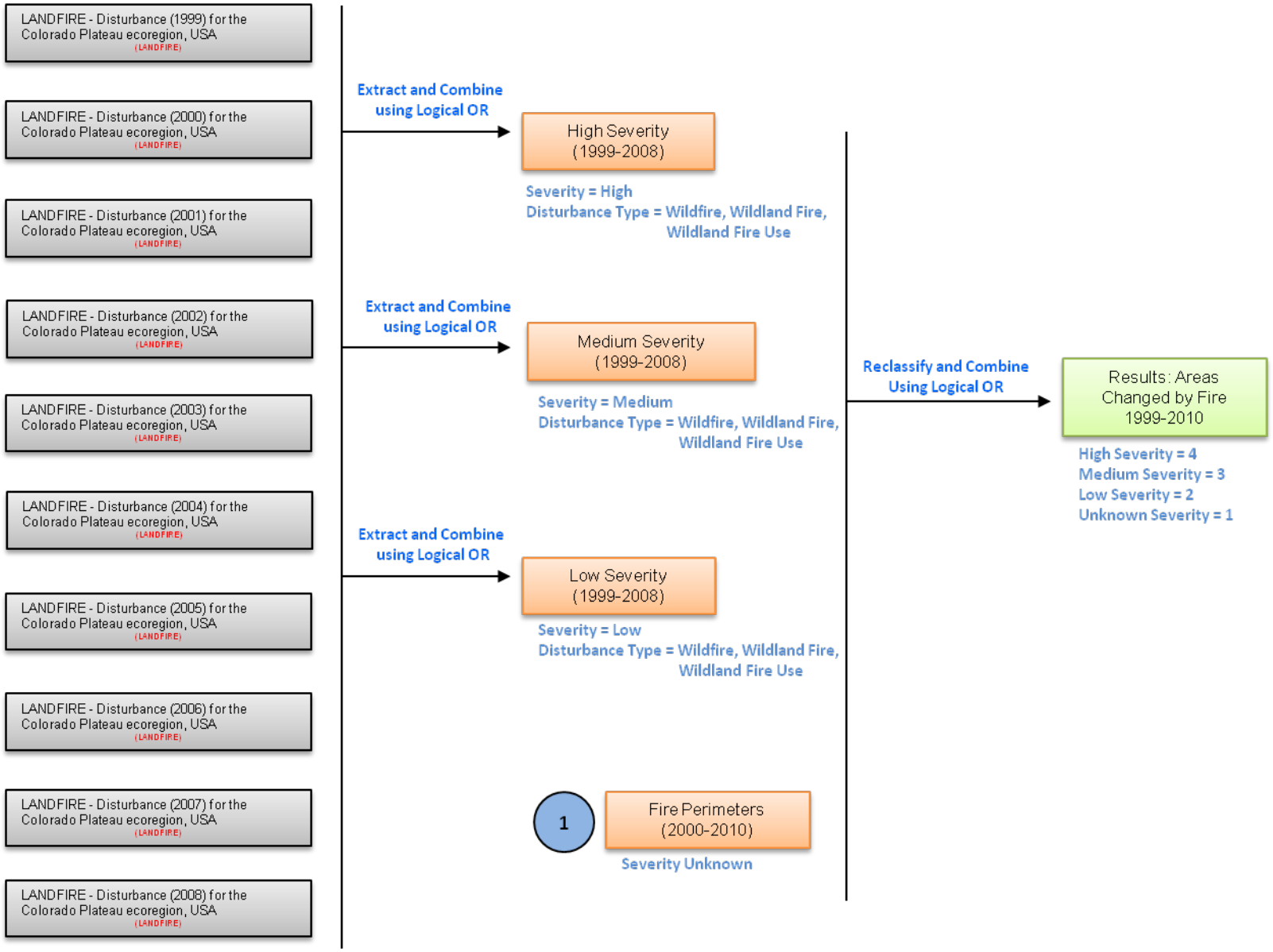
D. Species Conservation Elements – Management Questions
MQ D1. What is the most current distribution and status of available occupied habitat (and historic occupied habitat if available), seasonal and breeding habitat, and movement corridors (as applicable)?
MQ D6. What sites and movement corridors are vulnerable to change agents in the near-term horizon, 2025 (development, fire, invasive species) and long-term change horizon, 2060 (climate change)?
D. Wildlife Species Conservation Elements – Mammals: Go to Appendix C
Black-footed Ferret
Desert Bighorn Sheep
Gunnison's Prairie Dog
Mountain Lion
Mule Deer
Pronghorn Antelope
White-tailed Prairie Dog
D. Wildlife Species Conservation Elements – Birds: Go to Appendix C
American Peregrine Falcon
Burrowing Owl
Ferruginous Hawk
Golden Eagle
Greater Sage Grouse
Gunnison Sage Grouse
Mexican Spotted Owl
Yellow-breasted Chat
D. Wildlife Species Conservation Elements – Fishes: Go to Appendix C
Colorado Cutthroat Trout
Flannelmouth Sucker
Razorback Sucker

E. Wildfire
MQ E1. Where are areas that have been changed by wildfire between 1999 and 2009?

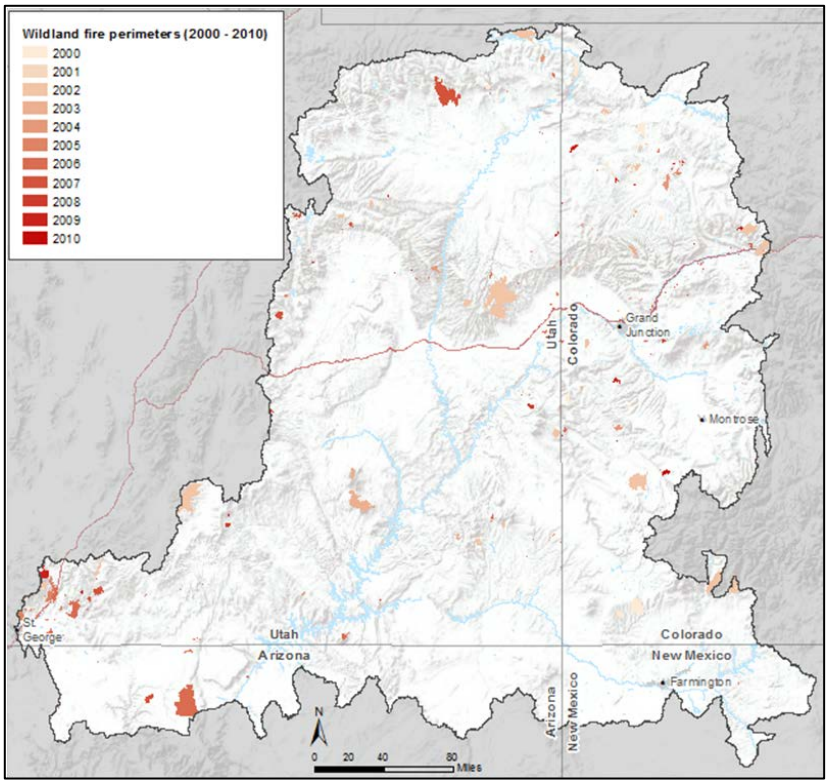
Process Model or Description

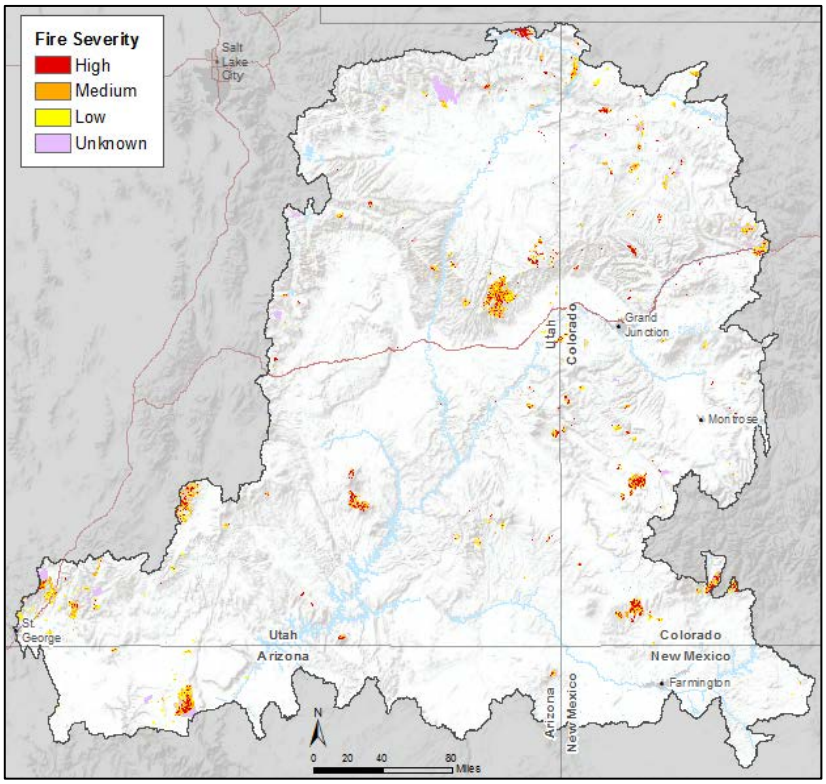
Merged fire perimeters from USGS for 2000-2010 with fire severity data obtained from LANDFIRE Disturbance datasets (1999-2008).




LANDFIRE - Disturbance (1999) for the Colorado Plateau ecoregion, USA (LANDFIRE)
LANDFIRE - Disturbance (2000) for the Colorado Plateau ecoregion, USA (LANDFIRE)
LANDFIRE - Disturbance (2001) for the Colorado Plateau ecoregion, USA (LANDFIRE)
LANDFIRE - Disturbance (2002) for the Colorado Plateau ecoregion, USA (LANDFIRE)
LANDFIRE - Disturbance (2003) for the Colorado Plateau ecoregion, USA (LANDFIRE)
LANDFIRE - Disturbance (2004) for the Colorado Plateau ecoregion, USA (LANDFIRE)
LANDFIRE - Disturbance (2005) for the Colorado Plateau ecoregion, USA (LANDFIRE)
LANDFIRE - Disturbance (2006) for the Colorado Plateau ecoregion, USA (LANDFIRE)
LANDFIRE - Disturbance (2007) for the Colorado Plateau ecoregion, USA (LANDFIRE)
LANDFIRE - Disturbance (2008) for the Colorado Plateau ecoregion, USA (LANDFIRE)
Extract and Combine using Logical OR
High Severity (1999-2008)
Severity = High
Disturbance Type = Wildfire, Wildland Fire, Wildland Fire Use
Extract and Combine using Logical OR
Medium Severity (1999-2008)
Severity = Medium
Disturbance Type = Wildfire, Wildland Fire, Wildland Fire Use
Extract and Combine using Logical OR
Low Severity (1999-2008)
Severity = Low
Disturbance Type = Wildfire, Wildland Fire, Wildland Fire Use
1
Fire Perimeters (2000-2010)
Severity Unknown
Reclassify and Combine Using Logical OR
Results: Areas Changed by Fire 1999-2010
High Severity = 4
Medium Severity = 3
Low Severity = 2
Unknown Severity = 1

Results for Wildfires 1999–2009



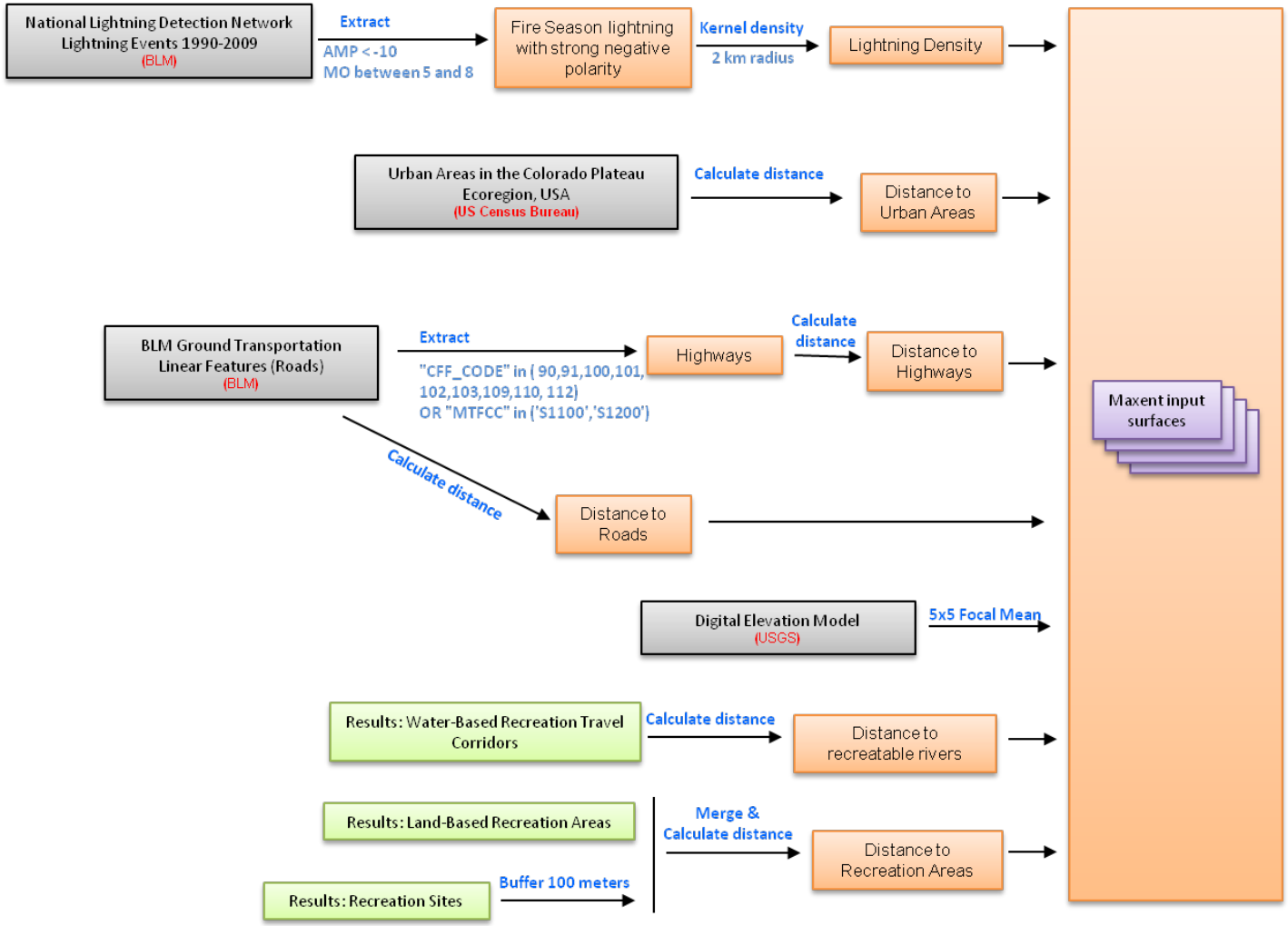


E. Wildfire
MQ E2. Where are areas with potential to change from wildfire?

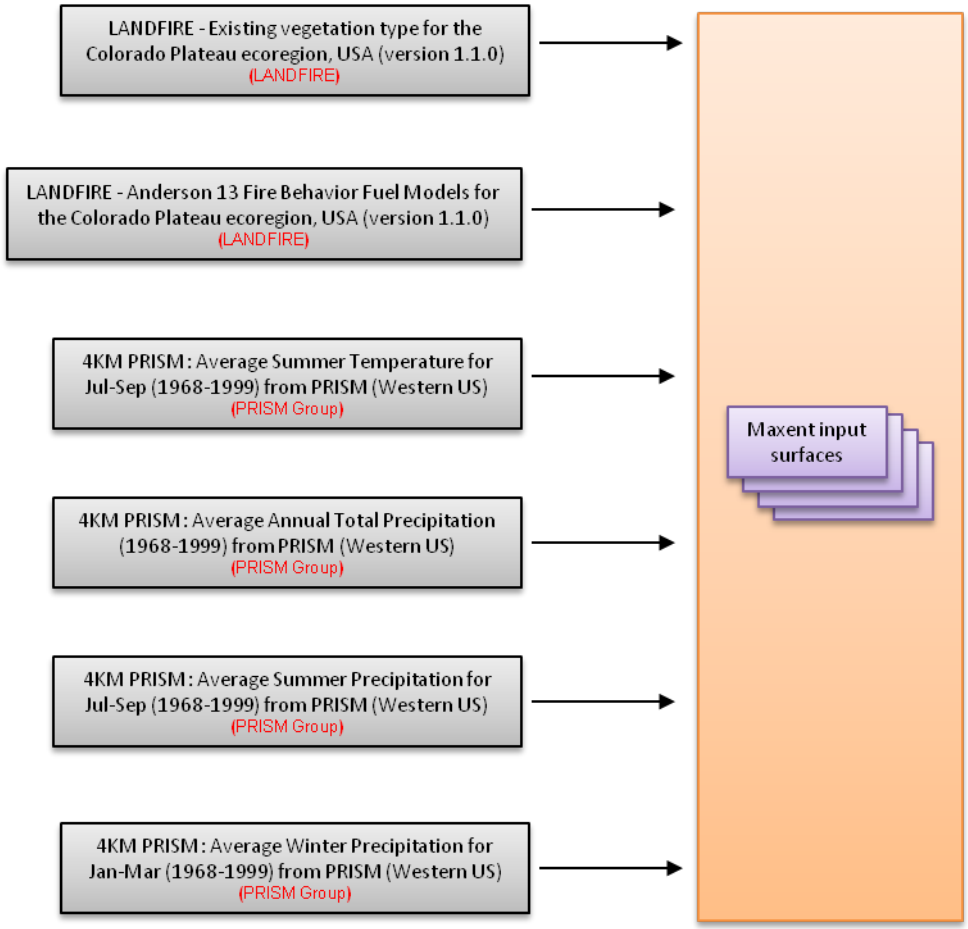
Process Model or Description

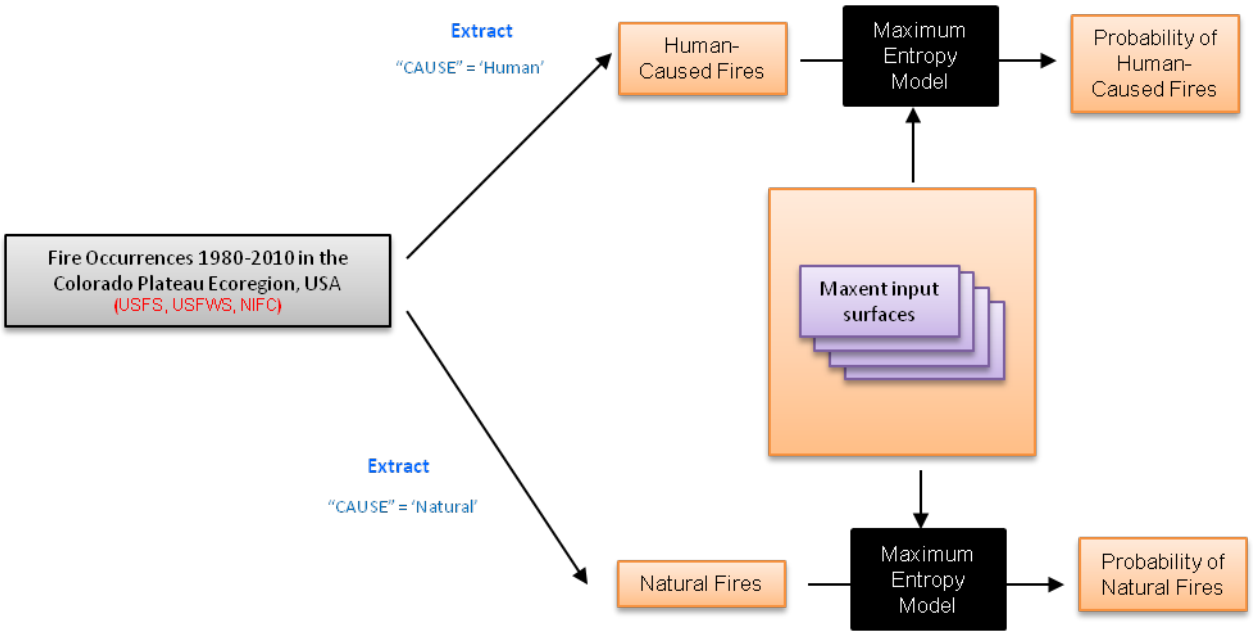
See process model for development of MaxEnt model based on current climate (PRISM) and landscape factors. Projected near-term (2015–2030) and long-term (2045–2060) results using this same model with near-term and long-term climate parameters obtained from RegCM3 regional climate model based on ECHAM5 boundary conditions. Other landscape factors were not changed for future projections. Calculated difference between near-term and long-term areas of high potential for fire occurrence compared to current areas of high potential.

Input Surface Creation

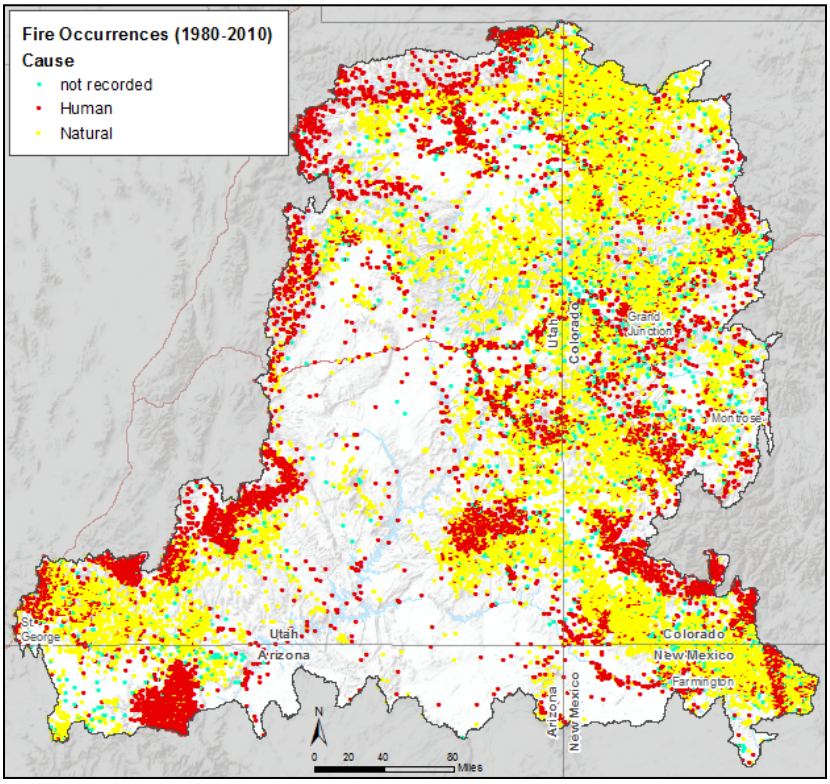


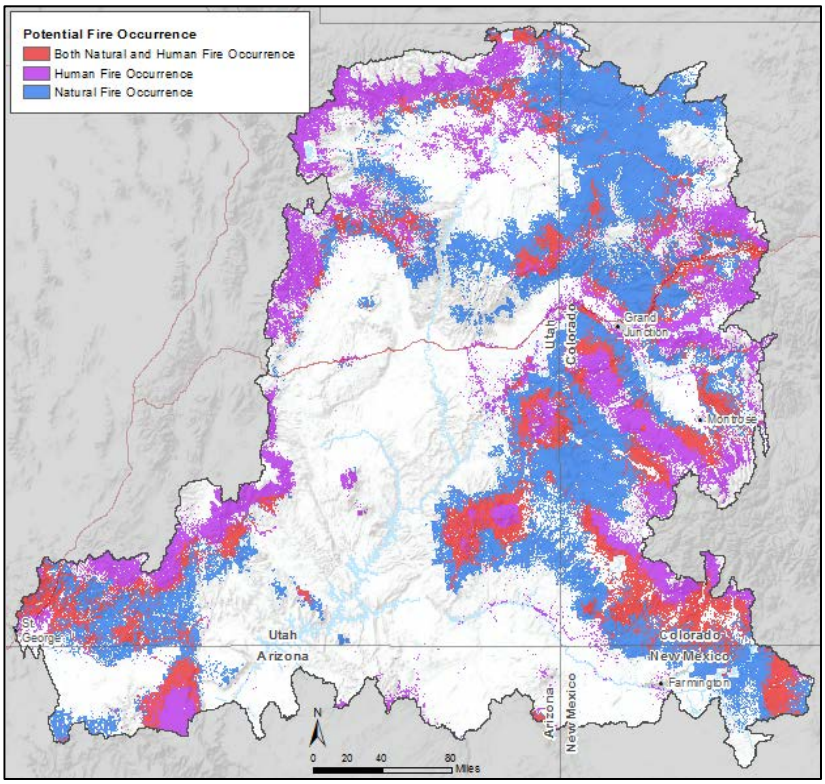
Input Surface Creation (continued)

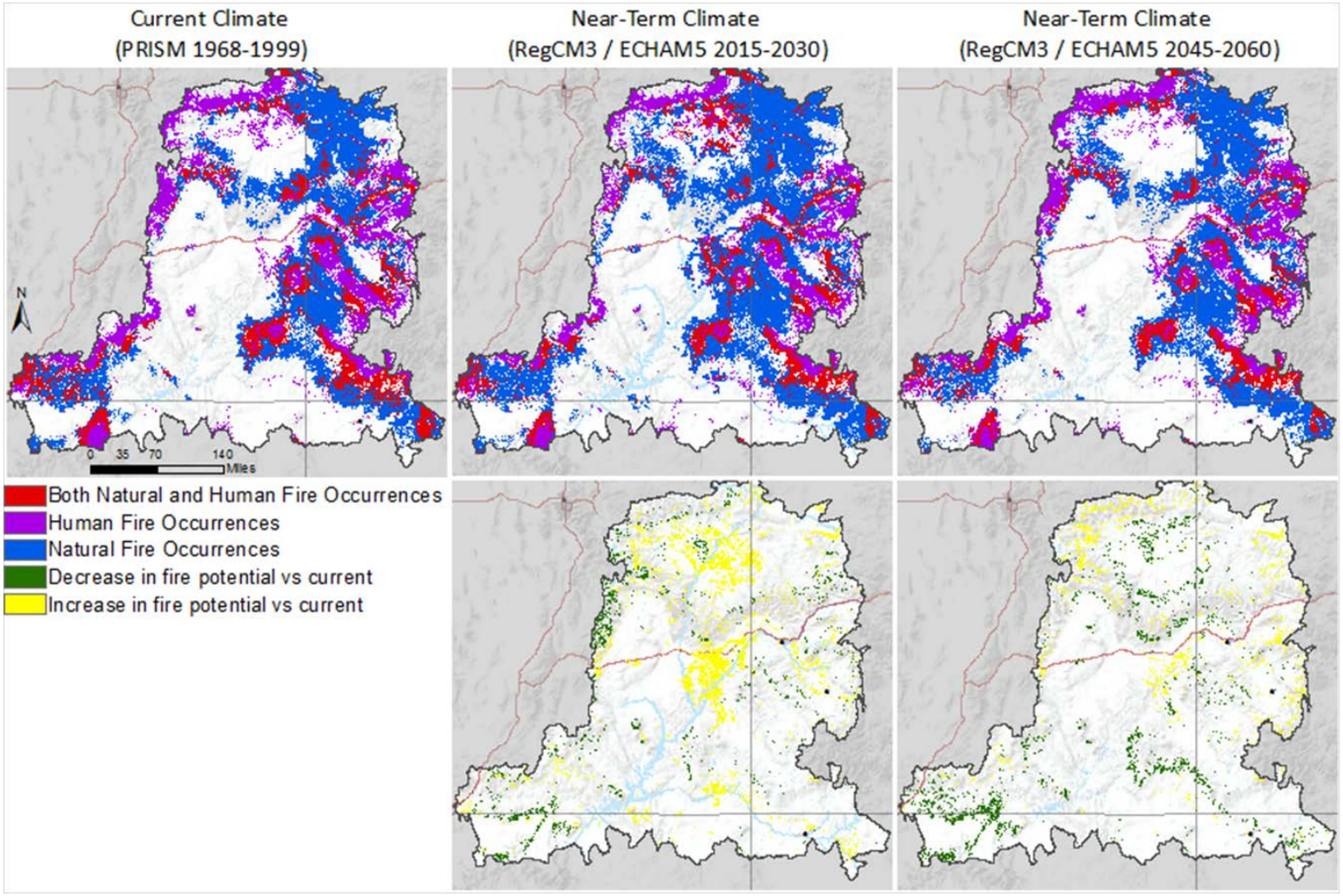



Extract
"CAUSE" = 'Human'
Human-Caused Fires
Maximum Entropy Model
Probability of Human-Caused Fires
Fire Occurrences 1980-2010 in the Colorado Plateau Ecoregion, USA
(USFS, USFWS, NIFC)
Maxent input surfaces
Extract
"CAUSE" = 'Natural'
Natural Fires
Maximum Entropy Model
Probability of Natural Fires

Results for Areas with Potential to Change from Wildfire

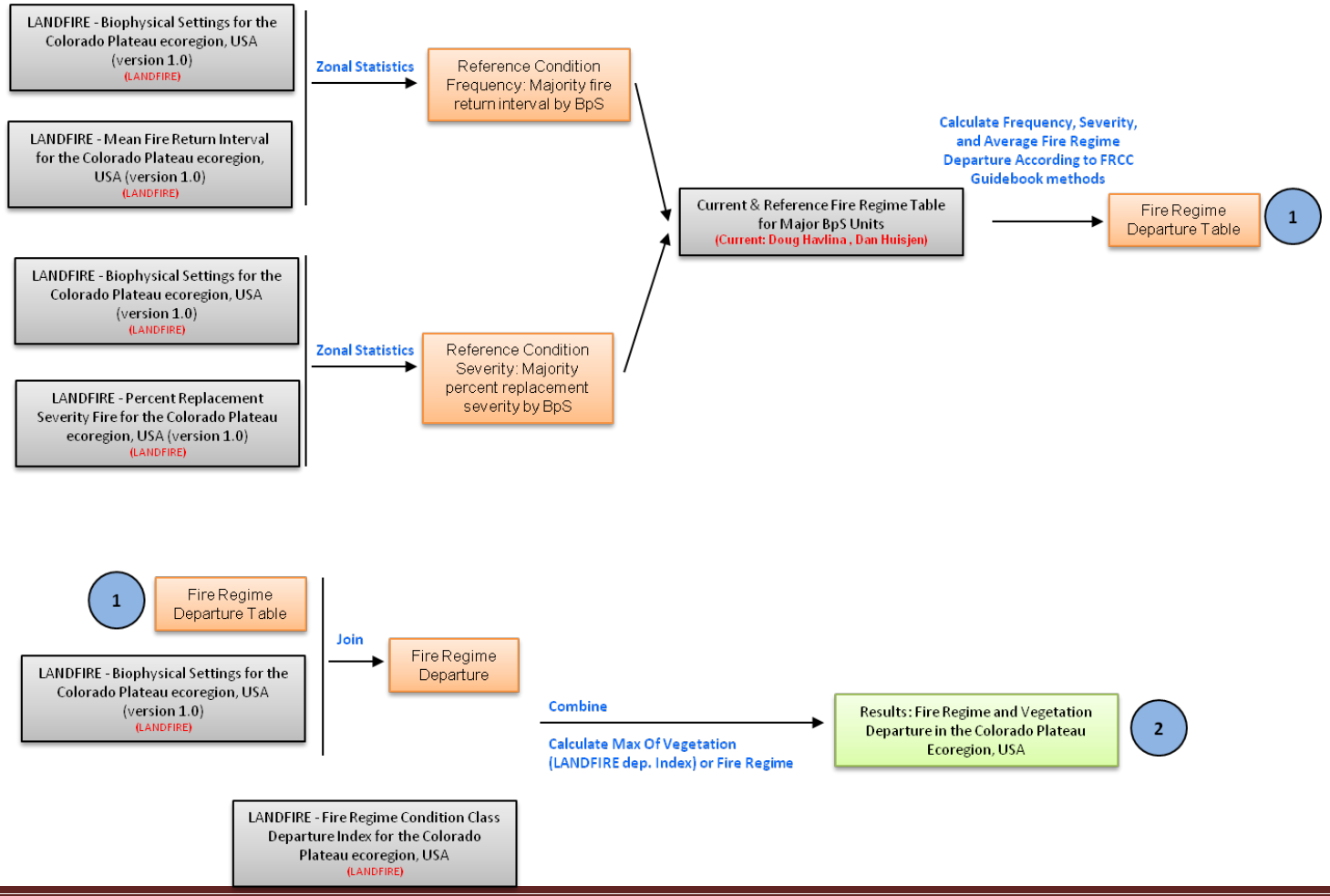





Current Climate
(PRISM 1968-1999)
Near-Term Climate
(RegCM3 / ECHAM5 2015-2030)
Near-Term Climate
(RegCM3 / ECHAM5 2045-2060)
N
0 35 70 140
Miles
Both Natural and Human Fire Occurrences
Human Fire Occurrences
Natural Fire Occurrences
Decrease in fire potential vs current
Increase in fire potential vs current

E. Wildfire
MQ E3. Where are the Fire Regime Condition Classifications?

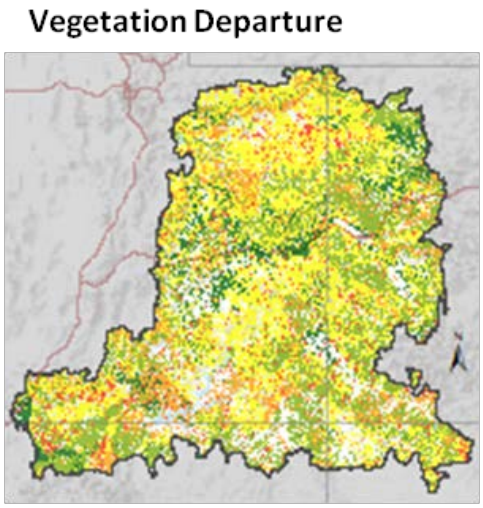
Process Model or Description

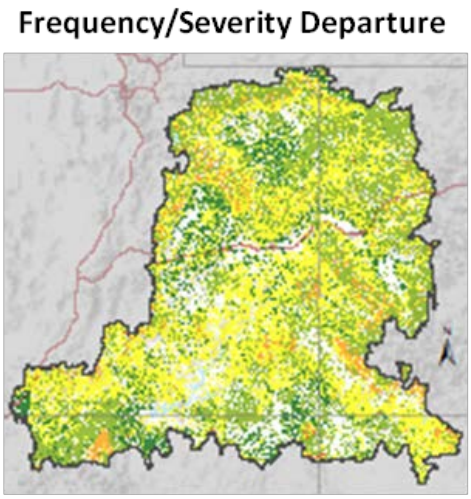


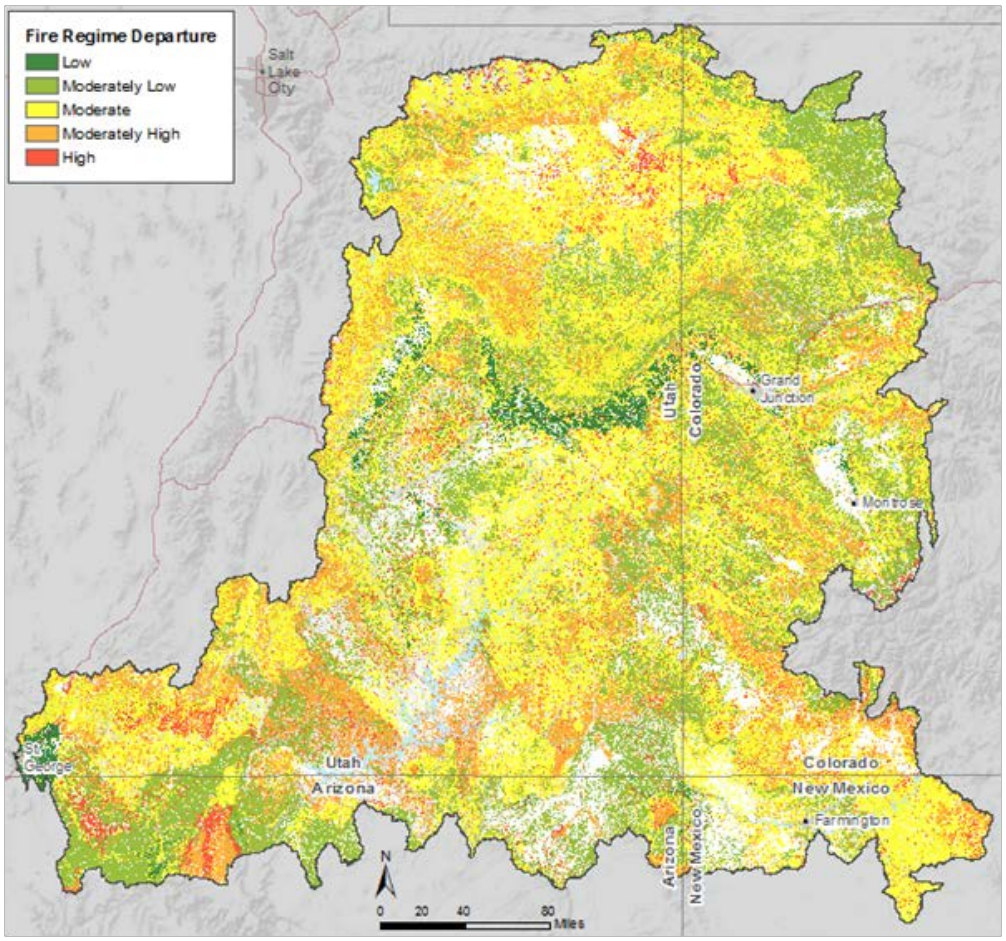
Biophysical Setting	Acres (1000s)	LANDFIRE Reference Condition Fire Return Interval	Current Fire Return Interval	LANDFIRE Reference Condition Replacement Fire Severity	Current Fire Severity	Mean Fire Frequency / Severity Departure
Inter-Mountain Basins Big Sagebrush Shrubland	8,389	151–200 Yrs	300 Yrs	76–80%	85–90%	27
Colorado Plateau Pinyon-Juniper Woodland	7,650	151–200 Yrs	250–300 Yrs	26–30%	76–80%	50
Inter-Mountain Basins Mixed Salt Desert Scrub	3,179	201–300 Yrs	201–300 Yrs	96–100%	96–100%	0
Colorado Plateau Blackbrush-Mormon-tea Shrubland	3,139	101–125 Yrs	101–125 Yrs	51–55%	80–85	18
Rocky Mountain Montane Riparian Systems	1,936	151–200 Yrs	151–200 Yrs	46–50%	46–50%	0
Rocky Mountain Gambel Oak-Mixed Montane Shrubland	1,783	51–60 Yrs	70–80 Yrs	66–70%	80–85%	22
Southern Rocky Mountain Ponderosa Pine Woodland	1,533	26–30 Yrs	75–100 Yrs	11–15%	46–50%	70
Southern Colorado Plateau Sand Shrubland	1,483	151–200 Yrs	151–200 Yrs	66–70%	66–70%	0
Rocky Mountain Aspen Forest and Woodland	1,323	51–60 Yrs	100–120 Yrs	41–45%	61–65%	41
Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	1,176	151–200 Yrs	200–250 Yrs	96–100%	96–100%	10
Inter-Mountain Basins Greasewood Flat	1,173	201–300 Yrs	201–300 Yrs	96–100%	96–100%	0
Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	891	36–45 Yrs	75–100 Yrs	11–15%	46–50%	70
Inter-Mountain Basins Montane Sagebrush Steppe - Mountain Big Sagebrush	852	51–60 Yrs	150 Yrs	96–100%	96–100%	32
Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland - High Elevation	674	51–60 Yrs	100–125 Yrs	46–50%	75–80%	44
Inter-Mountain Basins Semi-Desert Grassland	663	101–125 Yrs	101–125 Yrs	31–35%	31–35%	0
Inter-Mountain Basins Semi-Desert Shrub-Steppe	448	151–200 Yrs	151–200 Yrs	56–60%	56–60%	0
Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	444	51–60 Yrs	100–125 Yrs	41–45%	75–80%	48
Rocky Mountain Lower Montane-Foothill Shrubland	432	51–60 Yrs	75–100 Yrs	21–25%	46–50%	44
Colorado Plateau Mixed Low Sagebrush Shrubland	373	126–150 Yrs	150–200 Yrs	36–40%	36–40%	10

Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland - Low Elevation	324	26–30 Yrs	90–100 Yrs	21–25%	70–75%	70
Rocky Mountain Gambel Oak-Mixed Montane Shrubland - Continuous	265	61–70 Yrs	75–100 Yrs	71–75%	86–90%	20
Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland	235	40–55 Yrs	75–100 Yrs	16–20%	46–50%	65
Mojave Mid-Elevation Mixed Desert Scrub	162	301–500 Yrs	301–500 Yrs	96–100%	96–100%	0
Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland	155	51–60 Yrs	80–85 Yrs	21–25%	60–65%	48
Inter-Mountain Basins Montane Sagebrush Steppe - Low Sagebrush	153	51–60 Yrs	90–100 Yrs	96–100%	96–100%	21
Southern Rocky Mountain Ponderosa Pine Savanna	143	16–20 Yrs	80–100 Yrs	0–5%	41–45%	87
Inter-Mountain Basins Big Sagebrush Shrubland - Wyoming Big Sagebrush	126	151–200 Yrs	151–200 Yrs	96–100%	96–100%	0
Rocky Mountain Subalpine/Upper Montane Riparian Systems	105	151–200 Yrs	151–200 Yrs	26–30%	26–30%	0
Sonora-Mojave Creosotebush-White Bursage Desert Scrub	96	301–500 Yrs	301–500 Yrs	56–60%	56–60%	0
Colorado Plateau Pinyon-Juniper Shrubland	95	101–125 Yrs	150–175 Yrs	16–20%	71–75%	53
Rocky Mountain Subalpine-Montane Mesic Meadow	89	51–60 Yrs	90–100 Yrs	71–75%	71–75%	21
Rocky Mountain Alpine Turf	87	201–300 Yrs	201–300 Yrs	96–100%	96–100%	0
Rocky Mountain Lodgepole Pine Forest	82	151–200 Yrs	200–250 Yrs	91–95%	91–95%	10
Inter-Mountain Basins Montane Sagebrush Steppe	82	101–125 Yrs	200 Yrs	96–100%	96–100%	22
Inter-Mountain Basins Juniper Savanna	74	101–125 Yrs	101–125 Yrs	16–20%	16–20%	0
Southern Rocky Mountain Montane-Subalpine Grassland	64	31–35 Yrs	75–100 Yrs	16–20%	71–75%	69
Great Basin Semi-Desert Chaparral	59	101–125 Yrs	101–125 Yrs	96–100%	96–100%	0
Rocky Mountain Gambel Oak-Mixed Montane Shrubland - Patchy	51	71–80 Yrs	90–100 Yrs	21–25%	35–40%	30
Great Basin Pinyon-Juniper Woodland	47	61–70 Yrs	130–140 Yrs	31–35%	60–65%	49
Inter-Mountain Basins Big Sagebrush Steppe	46	101–125 Yrs	200–250 Yrs	86–90%	86–90%	25

Results for Fire Regime and Vegetation Departure

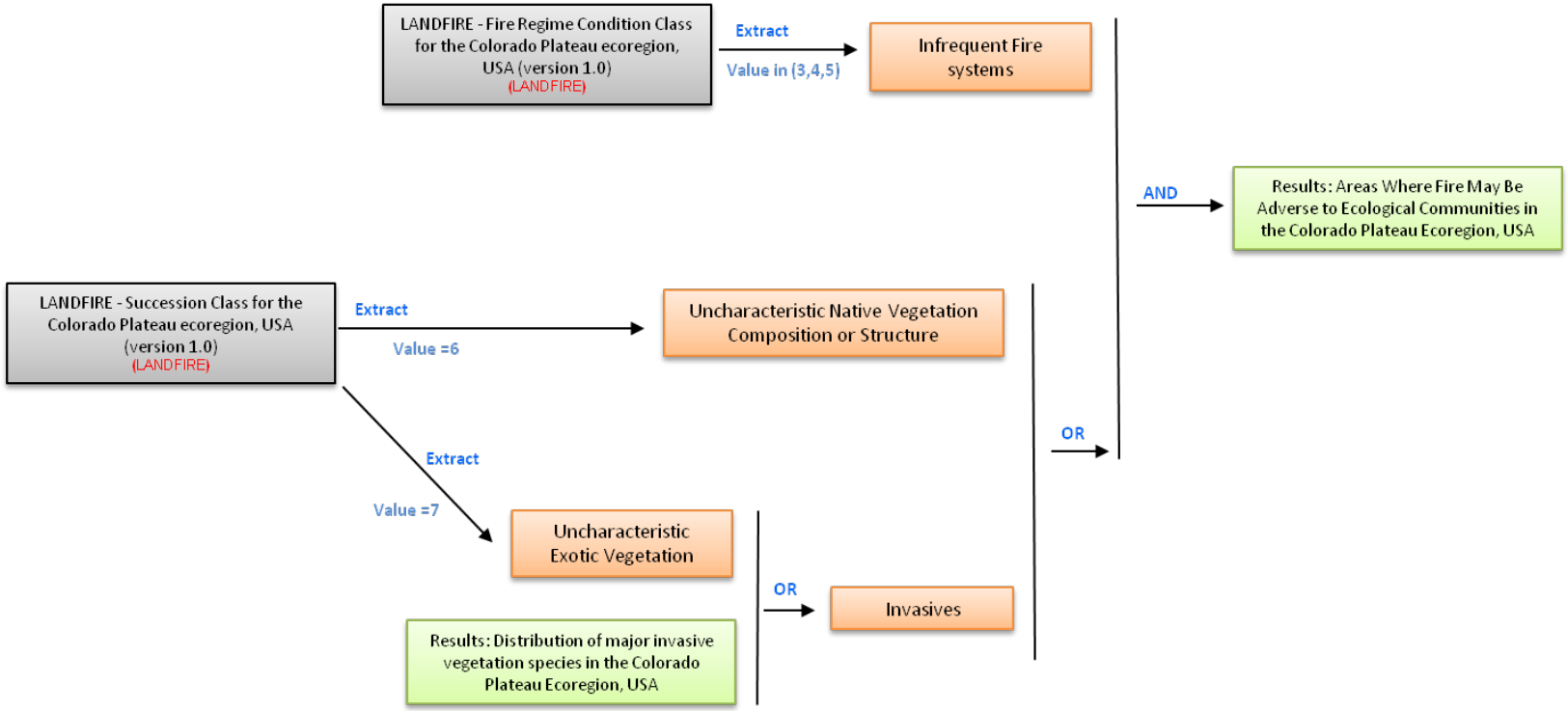




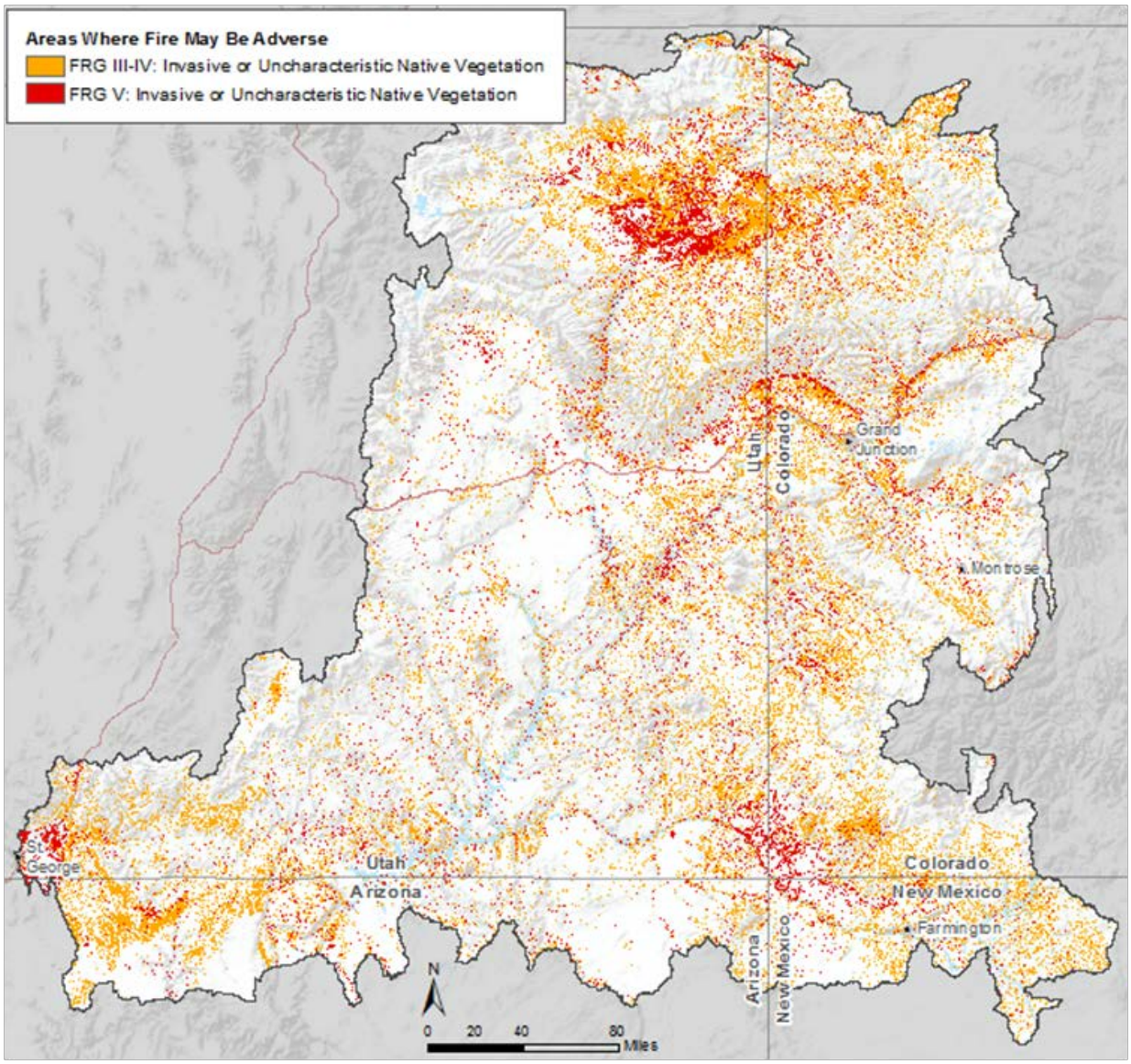


Wildfire E. Wildfire
MQ E4. Where is fire adverse to ecological communities, features, and resources of concern?

Process Model or Description



Results for Areas Where Fire is Adverse to Resources of Concern

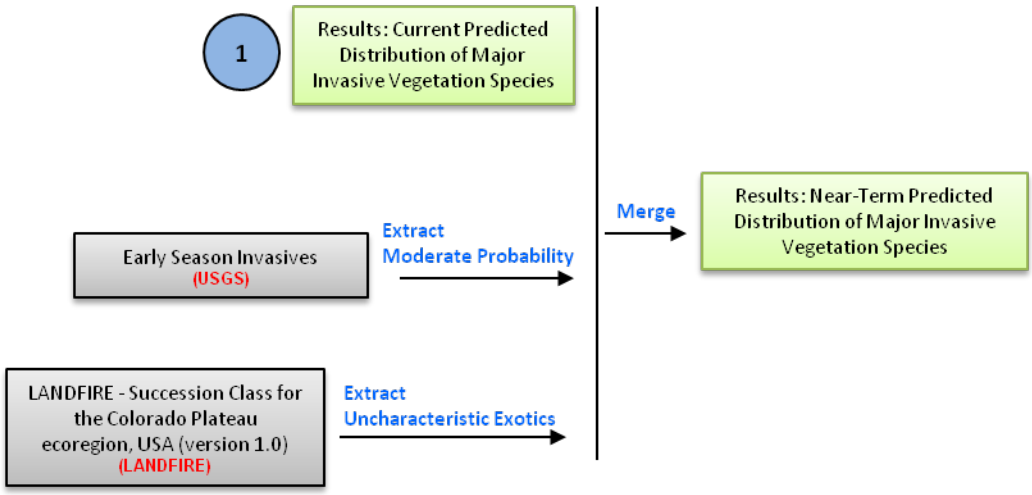


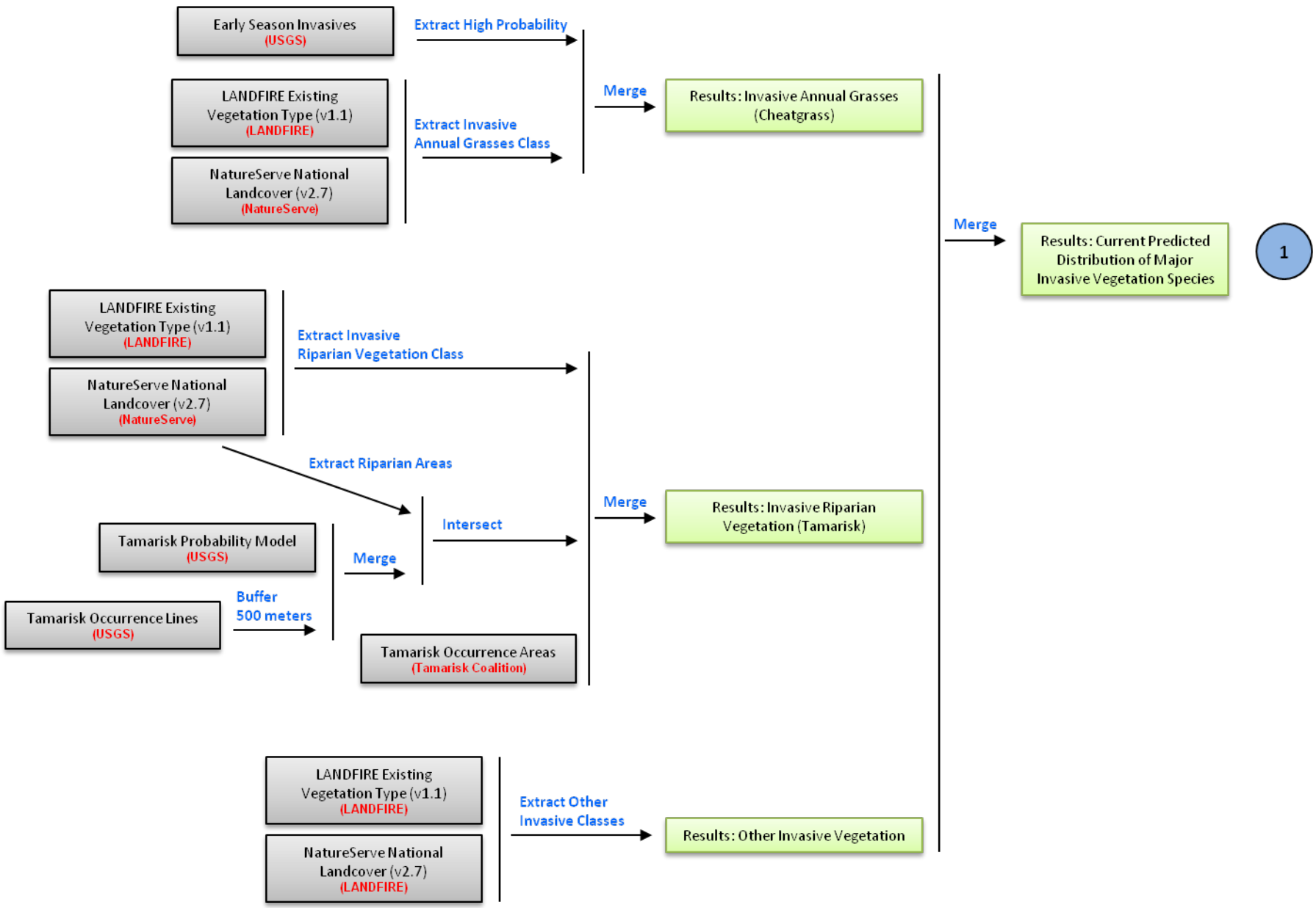
F. Invasive Species
MQ F1. Where are areas dominated by tamarisk and cheatgrass, and where are quagga, zebra mussel, and Asiatic clam present?

Process Model or Description

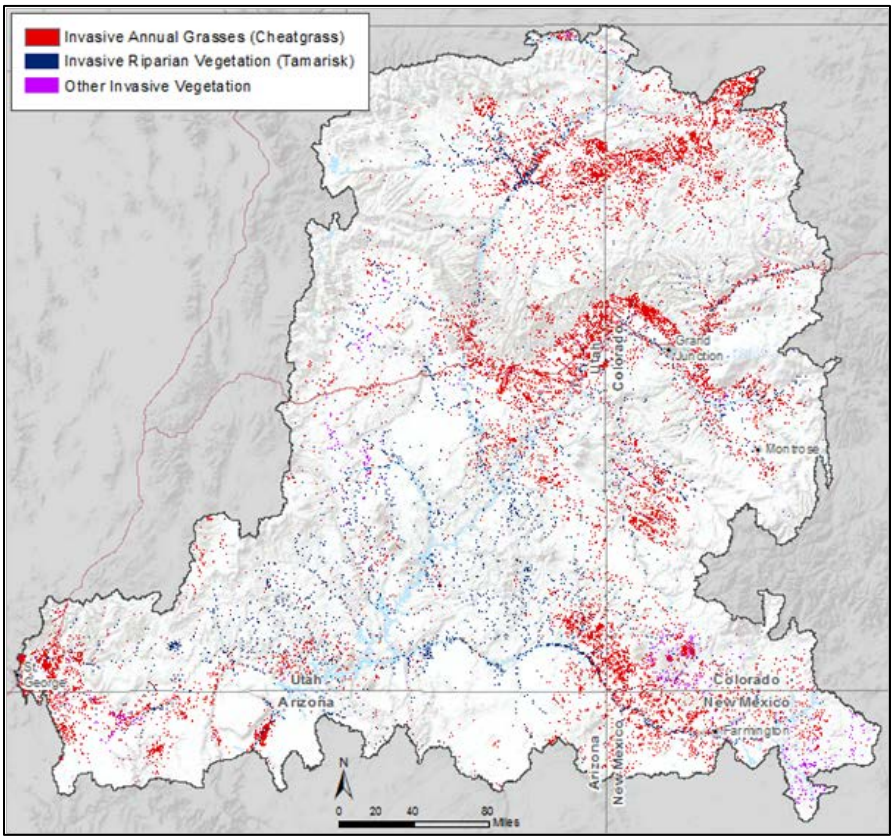
See process model for vegetation invasives. Aquatic invasives are simply selected from the USGS Nonindigenous Aquatic Species database (http://nas.er.usgs.gov/)

See next page for portion of process model marked with blue circled number 1 below:

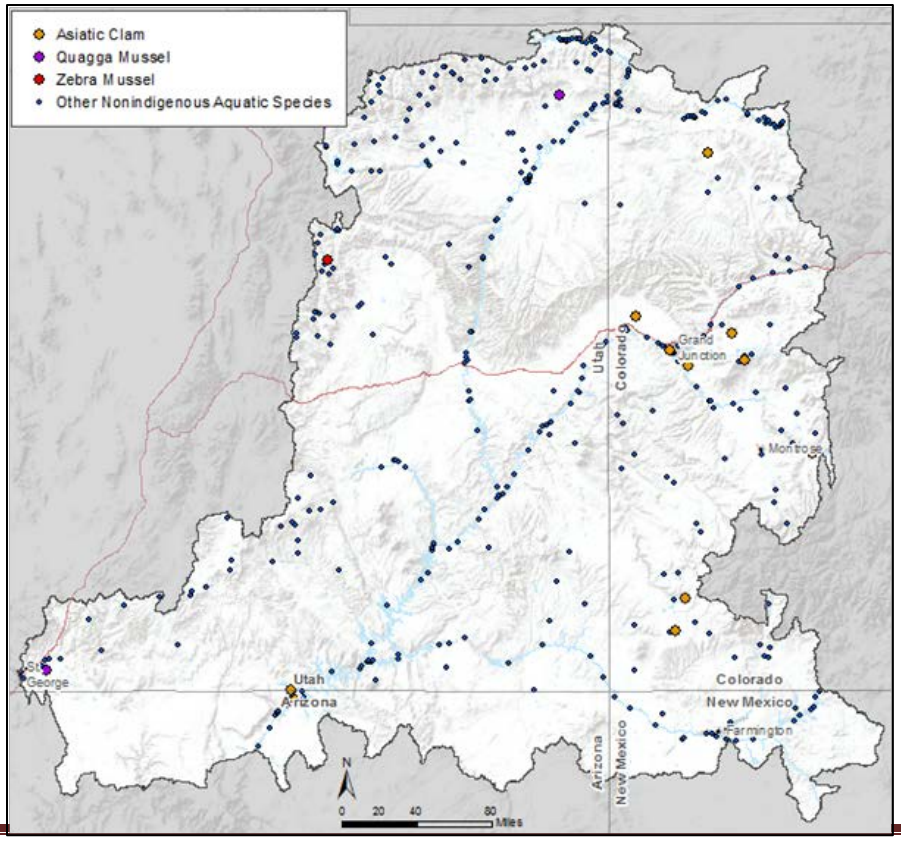



Early Season Invasives
(USGS)
Extract High Probability
LANDFIRE Existing Vegetation Type (v1.1)
(LANDFIRE)
NatureServe National Landcover (v2.7)
(NatureServe)
Extract Invasive Annual Grasses Class
Merge
Results: Invasive Annual Grasses (Cheatgrass)
Merge
Results: Current Predicted Distribution of Major Invasive Vegetation Species
1
LANDFIRE Existing Vegetation Type (v1.1)
(LANDFIRE)
NatureServe National Landcover (v2.7)
(NatureServe)
Extract Invasive Riparian Vegetation Class
Extract Riparian Areas
Tamarisk Probability Model
(USGS)
Merge
Intersect
Tamarisk Occurrence Lines
(USGS)
Buffer 500 meters
Tamarisk Occurrence Areas
(Tamarisk Coalition)
Merge
Results: Invasive Riparian Vegetation (Tamarisk)
LANDFIRE Existing Vegetation Type (v1.1)
(LANDFIRE)
NatureServe National Landcover (v2.7)
(LANDFIRE)
Extract Other Invasive Classes
Results: Other Invasive Vegetation

Results



Upland Invasive Annuals (Cheatgrass) and Invasive Riparian Vegetation (Tamarisk) with other Invasives from LANDFIRE

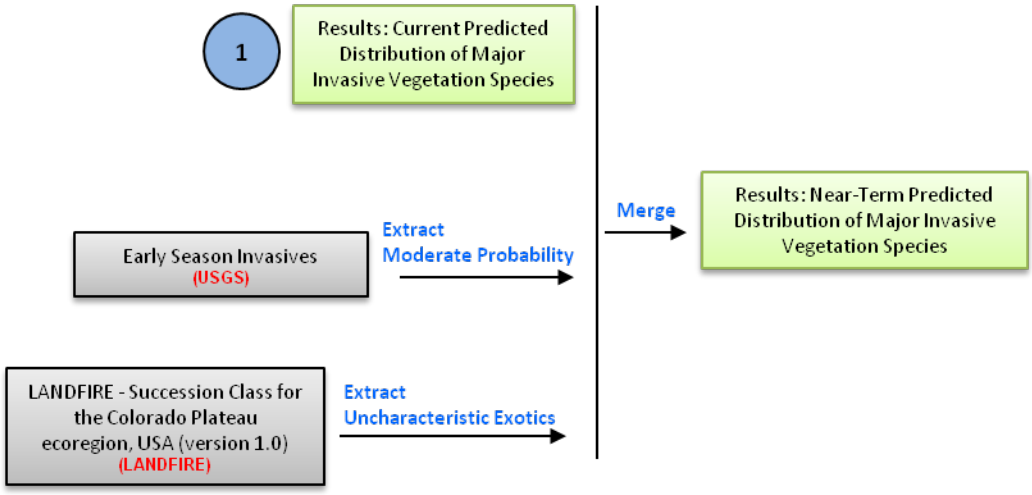


Aquatic Invasives: Asiatic clam (yellow dot), quagga mussel (red with blue outline), and zebra mussel (red dot): other non-native aquatic species (small blue dot).

F. Invasive Species
MQ F2. Where are areas of potential future encroachment from this invasive species?

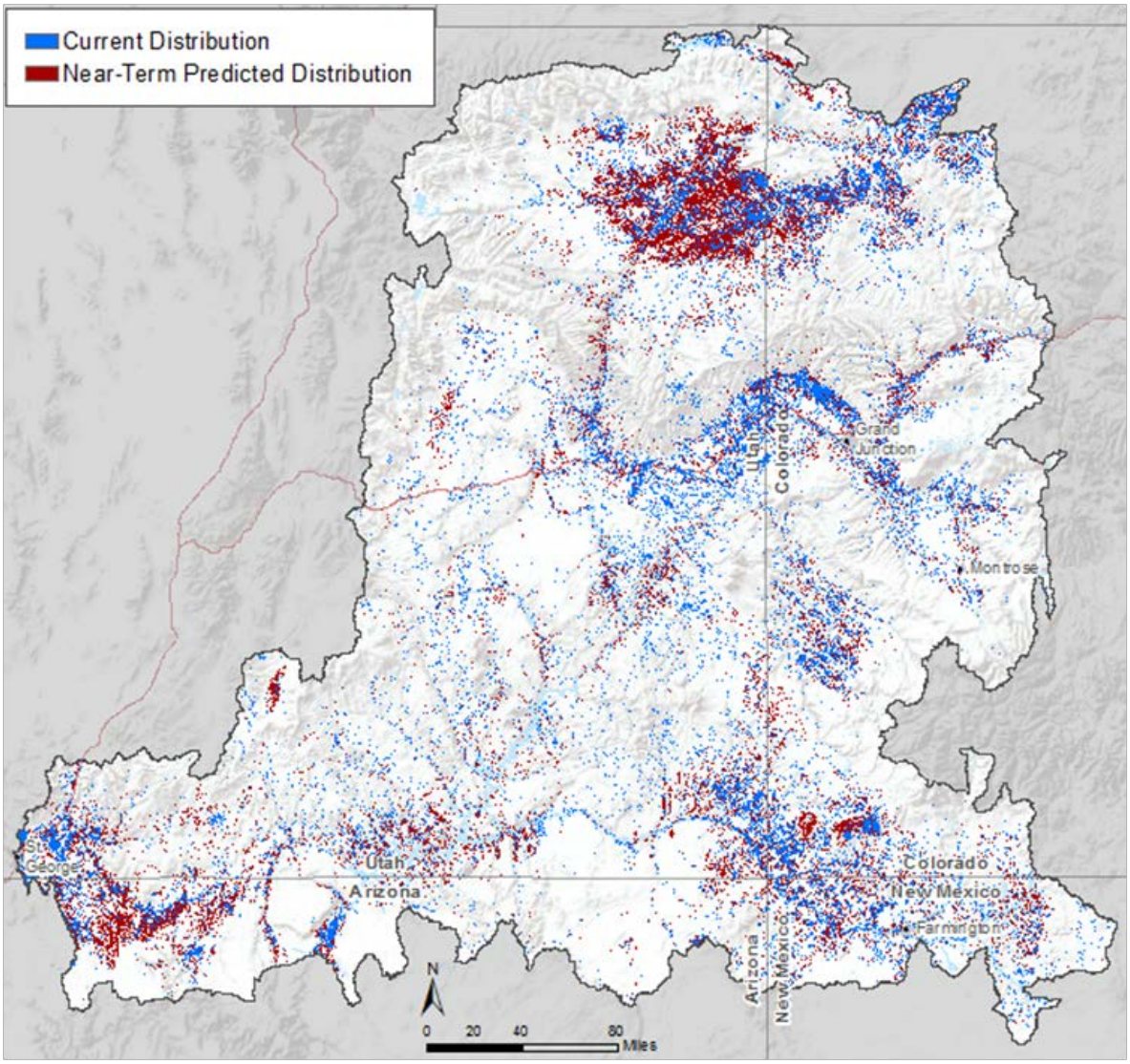
Process Model or Description

Process model for vegetation (below) is an extension of Process Model for MQ F1. MQF2 was not done for aquatic invasives due to insufficient data.



Results for Potential Future Encroachment of Invasive Species

Current Distribution and Near-term Future (2025) Predicted Distribution of Invasive Species



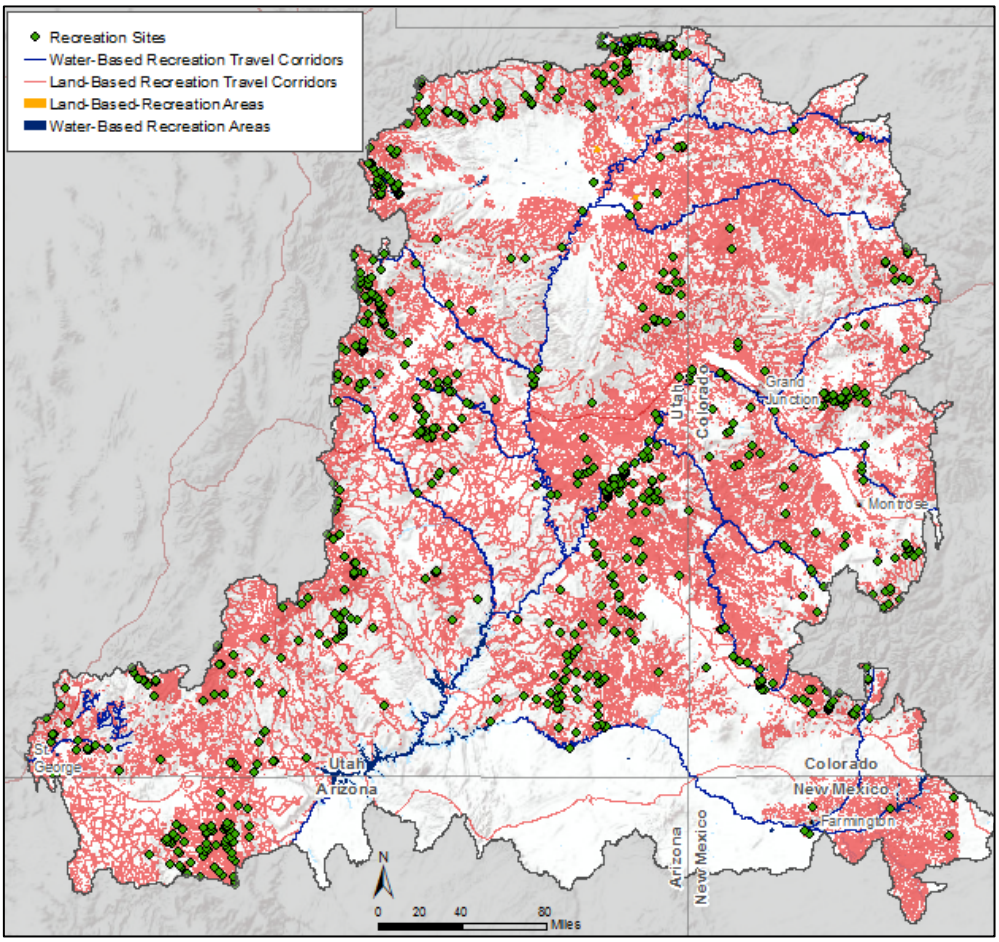
Current distribution in blue and near-term future (2025) distribution of invasive species in red.

G. Future Development
MQ G1. Where are areas of planned development? – **go to Appendix D**
MQ G2. Where are areas of potential development, including renewable energy and where are potential conflicts with conservation elements? – **go to Appendix D**
H. Resource Use
MQ H1. Where are high-use recreation sites, developments, roads, infrastructure or areas of intensive recreation use located (including boating)?

Process Model or Description

Recreation sites were compiled from USFS and BLM data. We compiled land-based recreation areas (open OHV areas) from BLM and water-based recreation areas by selecting larger water bodies from NHD (>1 square kilometer). Land-based travel corridors were extracted from BLM ground transportation linear features dataset within federal and state lands in Conservation Biology Institute protected areas database (excluding DOD lands). Water-based travel corridors were compiled by selecting rivers from NHD flowlines that were listed on BLM rivers website.

Results for High-Use Recreation

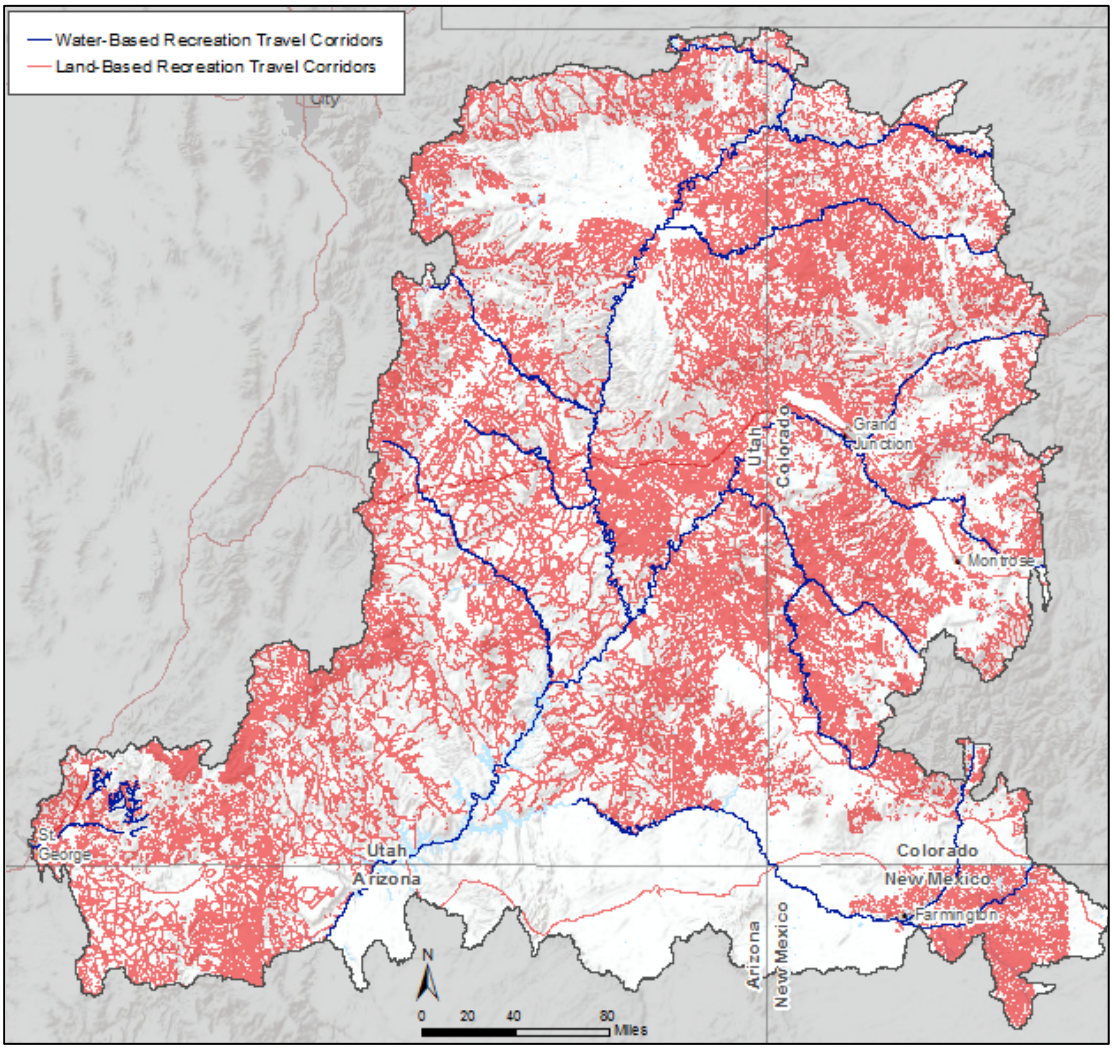


H. Resource Use
MQ H2. Where are areas of concentrated recreation travel (OHV and other travel) located?

Process Model or Description

Land-based travel corridors were compiled from BLM ground transportation linear features dataset within federal and state lands in Conservation Biology Institute protected areas database (excluding DOD lands). Water-based travel corridors were extracted by selecting rivers from NHD flowlines that were listed on BLM rivers website.

Results for Areas of Concentrated Recreation Travel

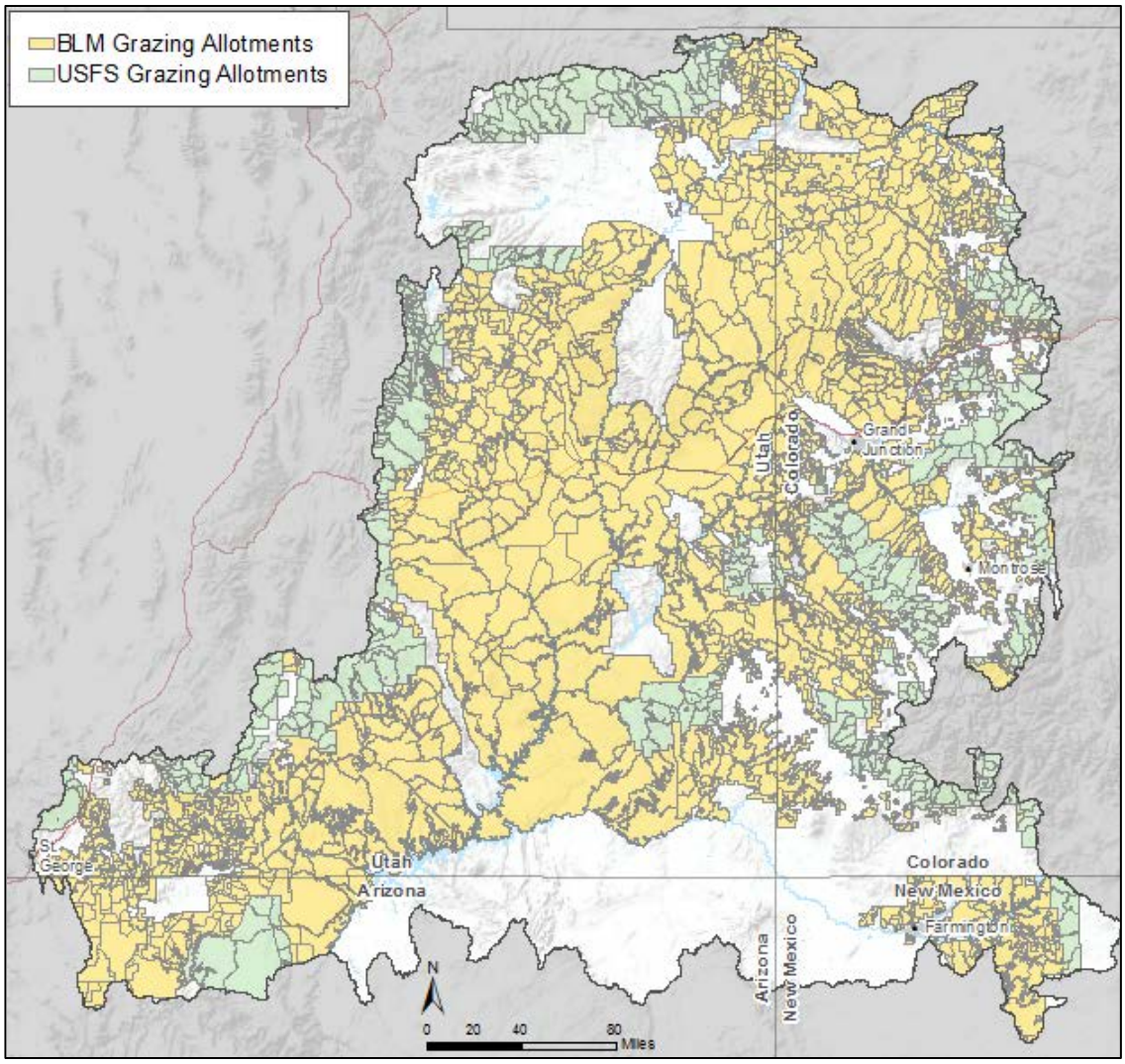


H. Resource Use
MQ H4. Where are allotments and type of allotment?

Process Model or Description

Grazing allotments were compiled from USFS and BLM datasets.

Results for Location of Grazing Allotments

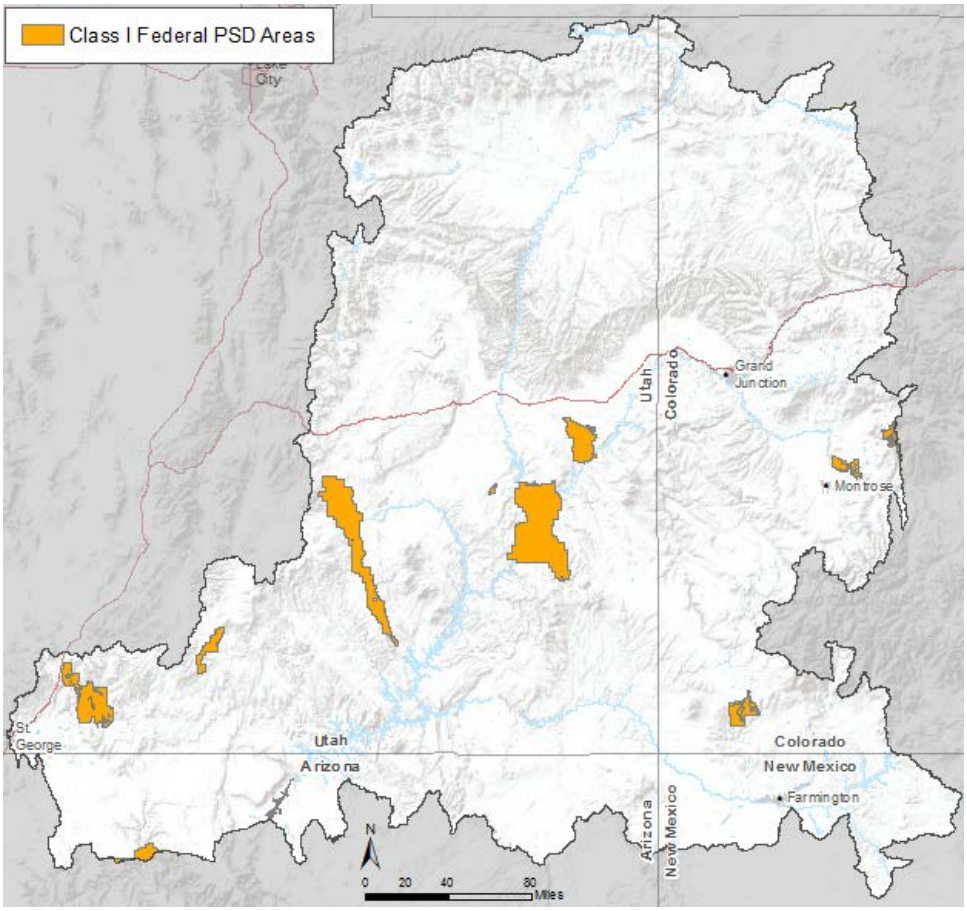


I. Air Quality
MQ I3. Where are the Class I PSD areas?

Process Model or Description

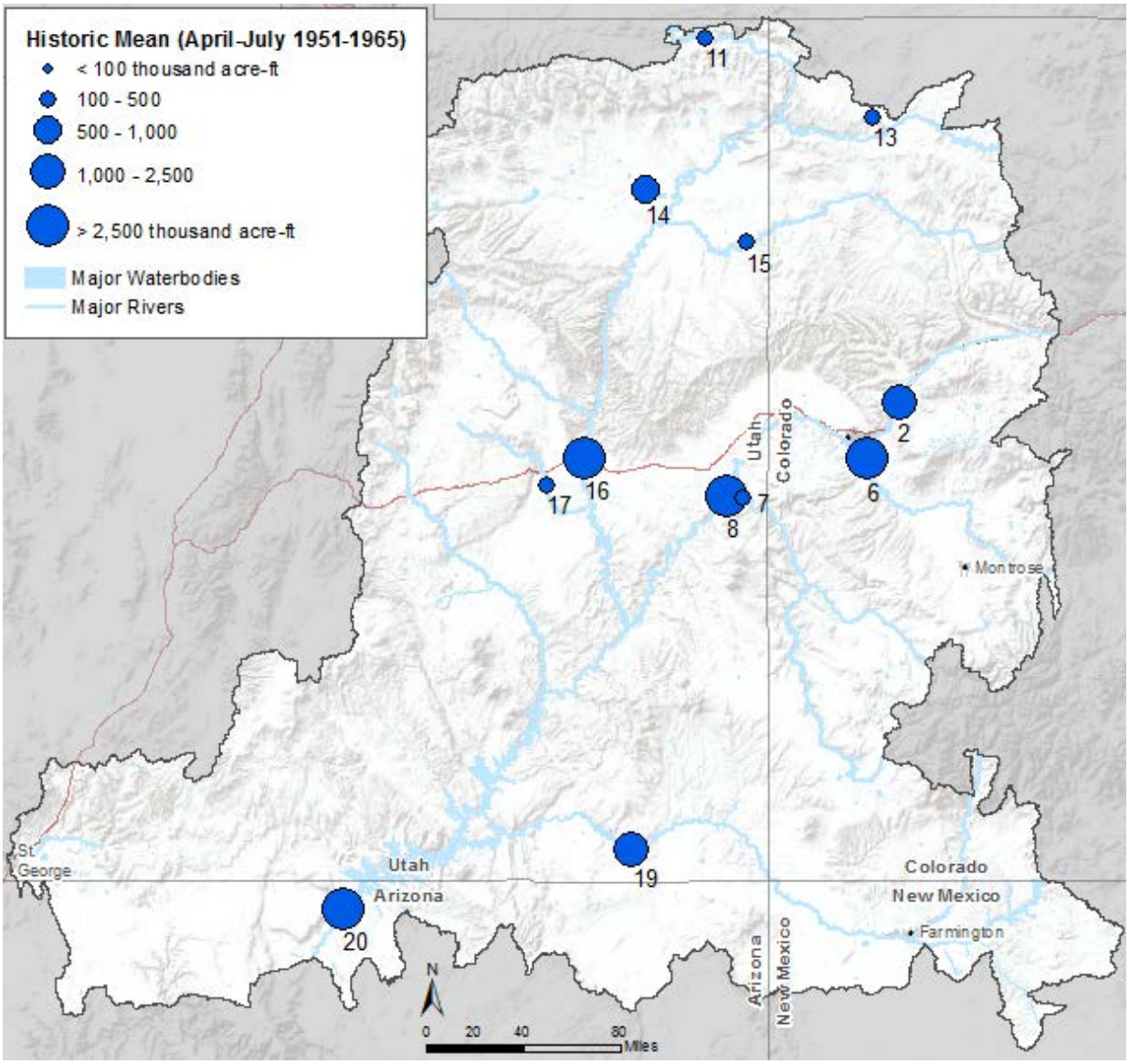
Federal Class I PSD areas selected from CBI protected areas database using authoritative list of areas (all national parks and some wilderness areas) from EPA.

Results for Class I PSD Air Quality Areas

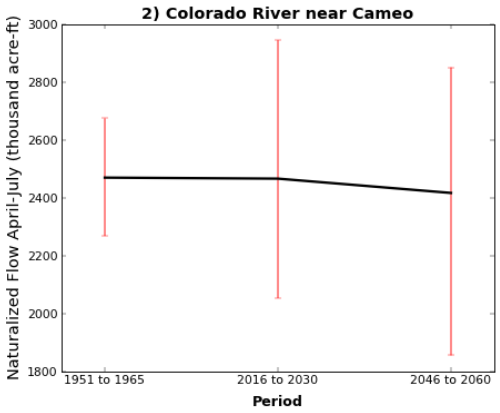


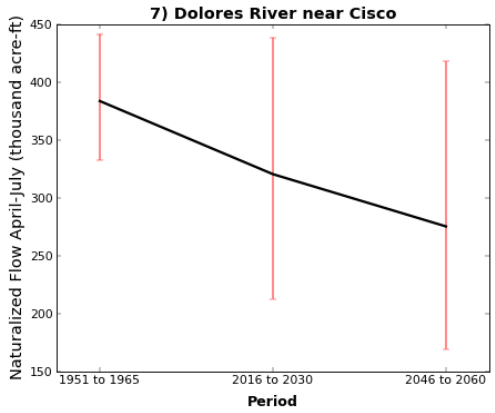
J. Climate Change
MQ J1. Where/how will the distribution of dominant native and invasive plant species be vulnerable to or have potential to change from climate change in 2060? – **see MQ C2 for each plant community**
MQ J3. Where are areas of species conservation elements distribute change between 2010 and 2060? – **see MQ D6 for each species**
MQ J4. Where are aquatic/riparian areas with potential to change from climate change? – **see MQ C2 for riparian vegetation and results below for future discharge**

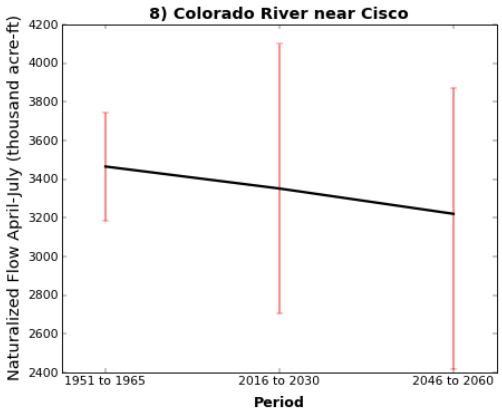
Results for Aquatic Areas with Potential to Change from Climate Change

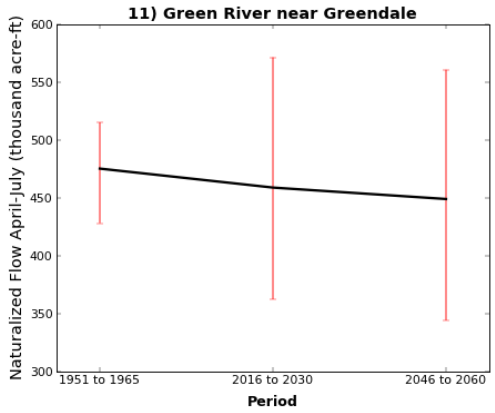


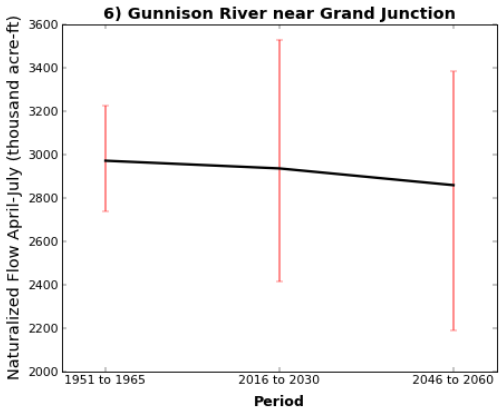
Graphs show alteration in flow at 12 gaging stations pictured above from historical period (1951) through current period and projected to mid-21st century (2060, Bureau of Reclamation data, BOR 2012). Graph numbers correspond to gaging station locations on previous map.

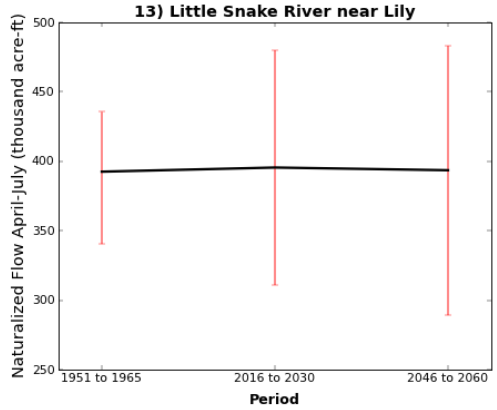


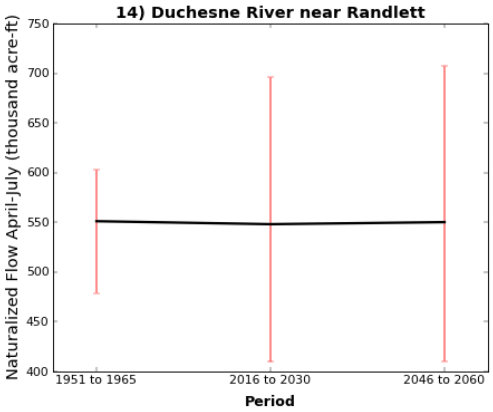


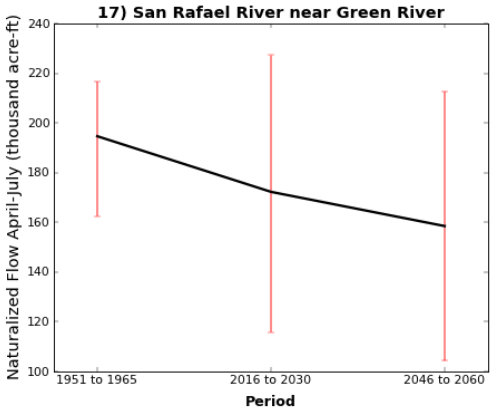


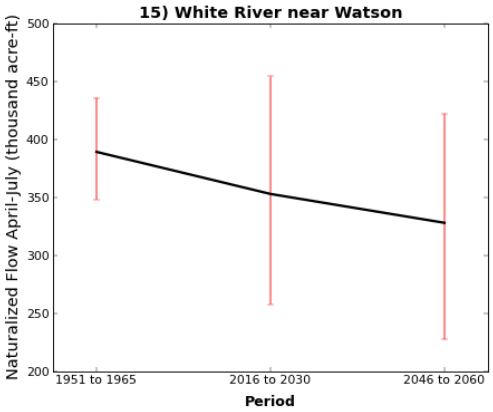


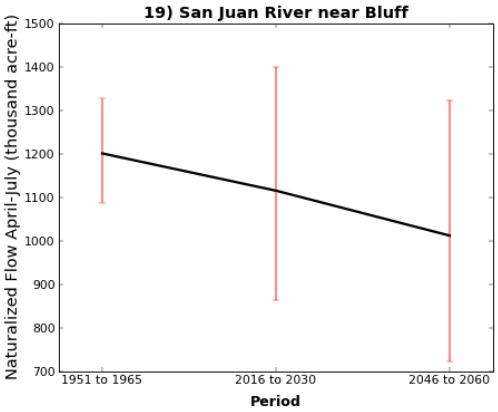


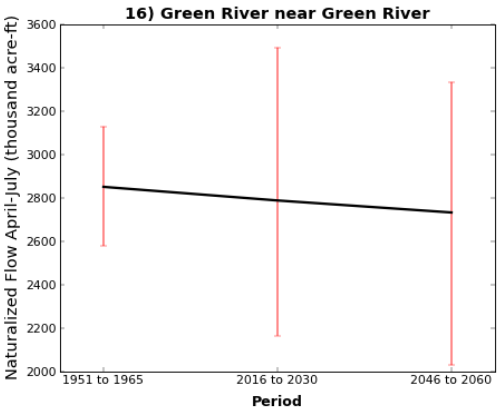


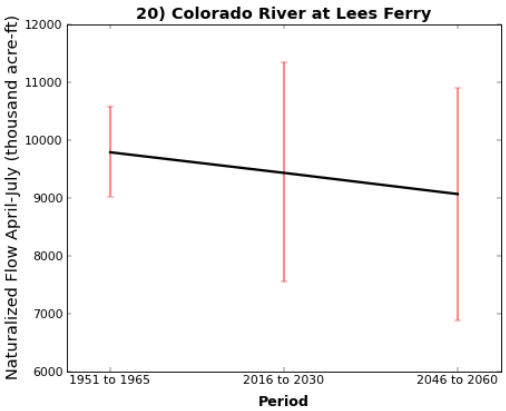












BOR (Bureau of Reclamation). 2012. Colorado River Basin water supply and demand study. Technical report B: Water Supply Assessment. Prepared by Colorado River Basin Water Supply and Demand Study Team, U.S. Bureau of Reclamation.