Regional Framework for Water-Resources Monitoring Related to Energy Exploration and Development

Prepared for BLM by

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September 30, 2007

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Introduction

The Bureau of Land Management (BLM) has initiated the development of a National Monitoring Strategy to improve the efficiency and effectiveness of the Bureau's inventory, monitoring, and assessment efforts. The BLM faces a substantial challenge in developing and implementing monitoring programs that are effective and efficient across multiple scales, and capable of satisfying multiple institutional and legal requirements associated with environmental compliance and land-use planning. The overall goal of this project is to develop, with BLM, a practical approach to integrated water-resources monitoring related to energy development that capitalizes on existing monitoring programs and readily available data and information. As a part of this effort, an evaluation of the Bureau's monitoring efforts in relation to energy development was initiated by a BLM energy team. Analysis from this group has noted that current monitoring generally focuses on compliance and effectiveness monitoring at the local-lease level (Falise and other, 2005). At times information may be incomplete, not analyzed, inaccessible, or not used in the decision making process (US DOI, Bureau of Land Management, 2005). Issues also arise from inconsistencies among field offices precluding larger scale status or trend analysis. As a result of these issues, BLM has elected to adopt the seven-step framework developed by Mulder and others (1999) as a guide for developing a regional water-resource monitoring framework that can be applied in any BLM Resource Area. In addition, information on adaptive management developed by Williams and others (2007) is being considered in the implementation of the monitoring framework. This Framework has been developed with energy development in mind, however, it could be applied to other development activities.

The seven-step framework, adapted from Mulder and others (1999), is used to guide development of the regional water-resource framework. The seven steps are as follows:

1. Specify monitoring goals and objectives.
2. Characterize anthropogenic stressors that may affect receptors and the parameters of interest.
3. Develop regional questions and conceptual models to describe the process and pathways, anthropogenic stressors may affect receptors.
4. Suggest indicators to measure the effects of anthropogenic stressors, and define information availability and needs.
5. Estimate the sensitivity of indicators to detect change, to guide final indicator choice and monitoring design.
6. Describe a process by which management can identify thresholds of change requiring a management response.
7. Identify clear connections between the overall monitoring program and the management decision process.

By using the seven-step framework, the monitoring plans can build on the lessons learned from the success and failures of previous monitoring programs by including critical components (Mulder and others, 1999). In addition, it provides a common framework to evaluate the potentially different objectives and resource management issues in the focal area. With any monitoring effort it will likely be necessary to prioritize the approach based on resources available to support data collection, data management, and data interpretation. Prioritization would be expected to follow the evaluation of specific water-resources issues that are identified as hydrologic concerns. This document consists of two chapters. Chapter 1 contains the proposed regional water-resource monitoring framework (the Framework). Chapter 2 demonstrates how the Framework could be applied, using the Piceance Creek and Yellow Creek Watersheds, Colorado as an example.

Chapter 1
Regional Water-Resources Monitoring Framework

The regional water-resources monitoring framework follows directly from the seven-step framework of Mulder and others (1999). A description of each step as it relates to water resources and specific objectives associated with each step are described in this chapter. The seven-step framework is summarized in Figure 1.

Step 1 – Specify monitoring goals and objectives

In addition to the BLM Land Health Standards and objectives defined in Resource Management Plans (RMPs), monitoring goals and objectives are generally driven by regulatory processes, litigation, and site-specific issues. For example, state water law and the Federal Clean Water Act, as administered by the States or EPA, guide the management of water quantity and quality in most cases. Also, it is important that the regulatory process be applied in the context of regional hydrology. The key to step 1 is to define clear objectives which need to be met. These provide the minimum criteria that must be met. Some typical project objectives may include:

- Do not cause impacts to beneficial uses of surface waters.
- Do not cause impacts to surface water availability.
- Do not cause impacts to the class of use of groundwater.
- Do not impact the availability of water at permitted sources (e.g. wells, springs, and streams).
- Do not cause or contribute to exceedences of numerical and narrative water-quality standards.

Step 2. Characterize anthropogenic stressors that may affect receptors and parameters of interest

Potential anthropogenic influences and disturbances related to energy development can be determined by reviewing the analysis in the Resource Management Plan and Environmental Impact Statements, which include information on Reasonably Foreseeable Development, conditions of approval, mitigation measures, and Best Management Practices. Examples of potential anthropogenic influences and disturbances are increased soil erosion resulting from surface disturbances such as road and pipeline construction and well-pad development, and depletion of stream or spring flow from aquifer dewatering. At this point in the process a wide net should be cast to capture all areas of concern. This is a brainstorming activity. All identified potential impacts should be recorded and then distilled down to "hydrologic concern statements." Each hydrologic concern statement should identify the potential source, pathway, parameter, and receptor related to each concern. These concerns will likely be based on each individual informal conceptual model of how the hydrologic processes work. The validity of concerns should not be evaluated at this stage. That process occurs in step 3. An example concern statement may read:

> Disturbance associated with the installation of pipelines may cause an increase in runoff and soil erosion. Eroded soil can then be carried via surface runoff to area streams, causing increases in turbidity, salinity, and suspended sediment loads and streambed aggradation. These changes can impact aquatic life and irrigation, which are identified beneficial uses for these streams.

In Step 2 hydrological concerns were identified. In Step 3 we strive to understand how anthropogenic stressors and receptors are linked and what effect stressors have on receptors. This is the core component of setting up a regional-monitoring strategy as it provides for an evaluation of the validity of concerns.

This allows the hydrologic concern statements to be categorized as 1) “Unlikely to cause noticeable impacts,” 2) “Likely to cause noticeable impacts, but low potential for unacceptable impacts,” and 3) “Potential to cause unacceptable impacts.” Each concern statement must first be broken down into a series of questions which address the source, parameter, pathway, and receptor. These questions should always address the likelihood of noticeable impacts and the potential for unacceptable impacts and can be cast in the hydrologic framework or the regulatory framework. The types of questions asked help determine the type and scope of the conceptual model needed. Note that since the conceptual model is qualitative, the questions asked need to be qualitative as well. If a strict conceptual model can not answer critical questions adequately, simple analytical models may be needed to enhance the conceptual model (see the “Regional Approach to Modeling Related to Energy Development: Case Study for Water-Quality and Erosion Modeling” in Appendix 1). Questions which may result from the concern statement example used in step 2 may include:

- Will the disturbance associated with pipelines cause increased erosion? If so, for what duration?
- Will the eroded soils be transported to area streams by runoff? If so, for what duration and over what distance?
- Will turbidity, salinity, and suspended sediment loads in receiving streams be affected by the introduction of eroded sediment from the disturbance?
- Are the changes in turbidity, salinity, and/or suspended-sediment loads likely to be noticeable?
- Do the changes in turbidity, salinity, and/or suspended sediment loads have the potential to impact beneficial uses like aquatic life or irrigation?

Step 3 –Develop regional questions and conceptual models to describe the process and pathways, anthropogenic stressors may affect receptors.

A conceptual model is a tool to qualitatively describe the function of a hydrologic system, to anticipate the effects of anthropogenic stressors, and to inform the development of a regional monitoring plan. To develop a conceptual model, consideration is given to hydrologic inputs (e.g. precipitation, surface runoff baseflow), hydrologic pathways (e.g. watershed geomorphic characteristics, drainage network, ground-water flow paths, geology), hydrologic processes (e.g. ground-water recharge and discharge, hillslope and channel erosion, biogeochemical reactions, mixing, time and travel), and the anticipated stresses that the system will undergo.

Conceptual models should be comprehensive, internally consistent descriptions of how hydrologic systems are understood and function. Initially, conceptual models are based on a synthesis of available data; however, these models should be refined as new information becomes available throughout the life of the project. In some cases additional data collection will be needed to enhance a particular component of a conceptual model; however, this is typically the exception rather than the rule. Often conceptual models will aid in determining data gaps which can be filled during monitoring activities. Conceptual models should be comprehensive, internally consistent descriptions of how the systems are understood to function. At a minimum, the conceptual models should provide adequate answers to the questions posed.

The specific objectives of Step 3 are:

1) Develop a range of water-resources questions related to hydrological concerns from energy development,
2) Evaluate the available hydrologic information needed to develop the conceptual model. This information includes, but is not limited to: climate data, topographic and geologic maps, streamflow and ground-water level data, water-quality data, aquatic biology, land-health assessments, and reasonable foreseeable development,
3) Identify gaps in the available information that will be addressed in the monitoring plan that is to be developed,
4) Apply the conceptual model to the project area to qualitatively understand how/if, and through what pathways, anthropogenic stressors affect receptors,
5) Apply the conceptual models to determine if the impacts are likely to be noticeable, and if they have the potential to cause unacceptable impacts, and
6) Recognize that the conceptual model should be re-evaluated as new information becomes available.

Step 4 – Suggest indicators to measure the effects of anthropogenic stressors and define existing information availability and needs

An indicator is a parameter that can be measured and represents the condition of a receptor in the hydrologic system. The best indicators are those that are easily obtained, are sensitive to the effects of anticipated anthropogenic stressors, and are closely linked to the receptor of concern. Indicators can be defined by the regulatory framework in the project area (e.g. surface water-quality standards). In addition, the Resource Area Land-Use Plan, Land Health Standards, and specific applications for development and related stipulations can help identify indicators. Proxy indicators are surrogate parameters which generally reflect the status of some other important water-resources parameter. For example, specific conductance (SC) is generally proportional to total dissolved solids (TDS). It is often useful to use proxies as indicators since proxies may be easier to obtain.

It is important to note that some indicators, such as ground-water levels and sediment yields, may not be regulated but are key measures of regional water-resource response or are particularly sensitive to identified energy-development scenarios. Additional examples of indicators would be streamflow and concentrations of specific water-quality constituents such as dissolved metals, dissolved solids, and organic carbon, and suspended sediment. For regulated and unregulated indicators, it is important to evaluate indicator measurements in the context of natural variability in the hydrologic system. A further consideration in selecting indicators is the anticipated spatial and temporal scale of impact on regional water resources for a given stressor-receptor couple (see Step 2). Higher priority may be given to indicators that measure broad scale impacts than to indicators of local scale or short-term and long-term impacts. Once indicators are identified, available information needs to be assembled to characterize baseline conditions for a particular indicator. In the absence of these data an attempt should be made to identify surrogate indicators for which information is available and/or to identify the data gaps that will be addressed in the monitoring plan that is to be developed.

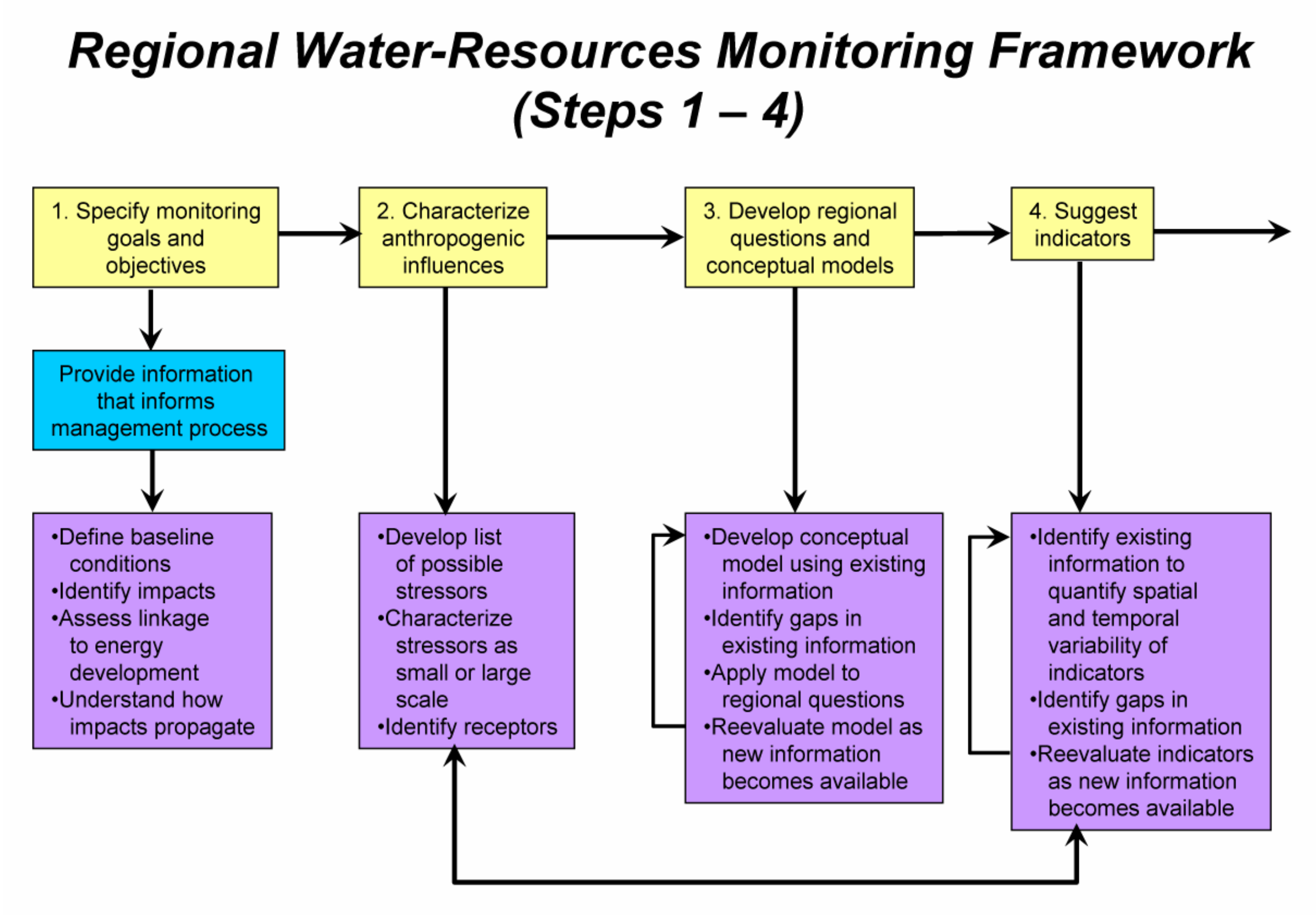


Figure 1. Flow chart summarizing the regional water-resources monitoring framework and the interrelations among steps 1 through 7

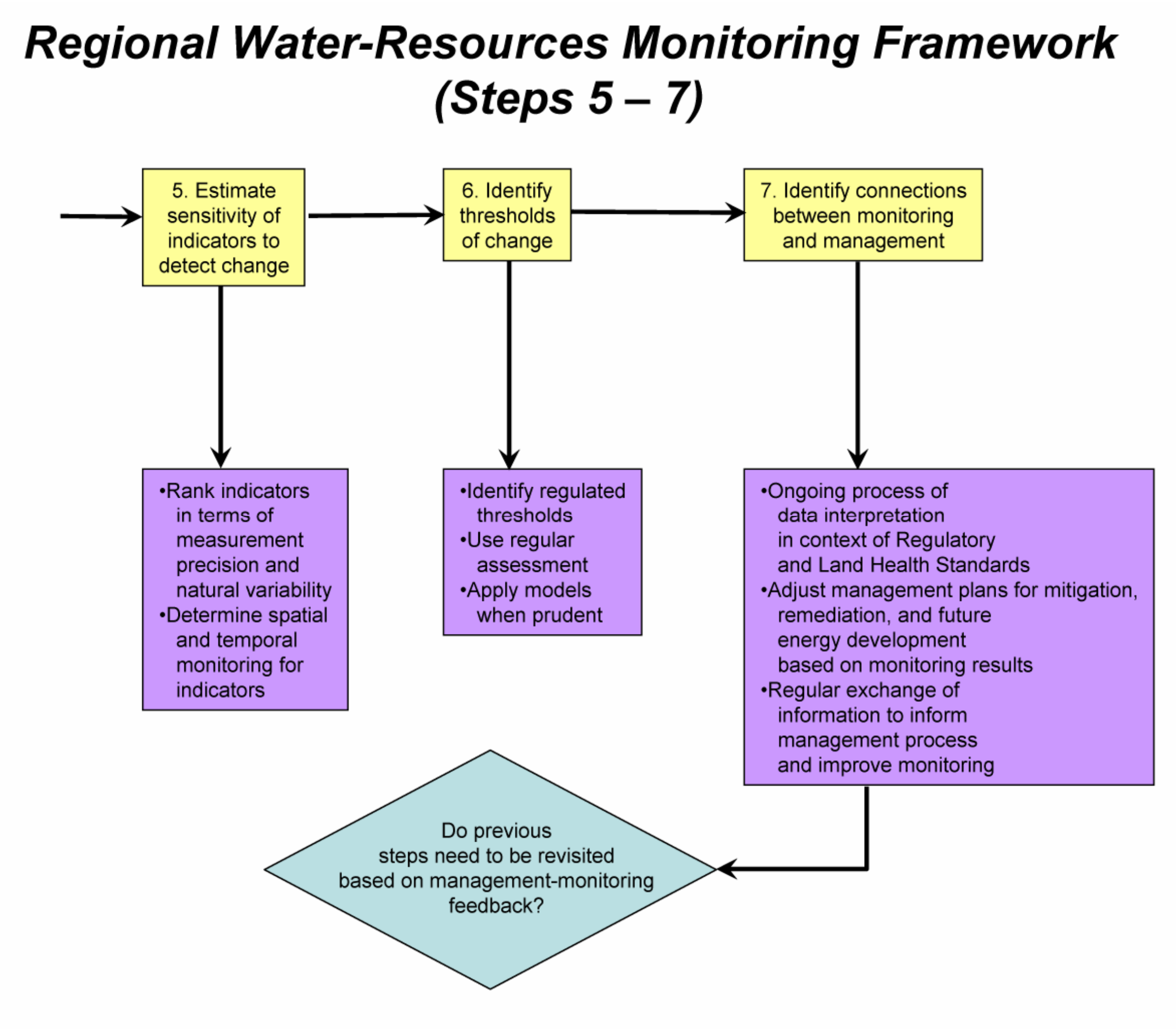


Figure 1. Flow chart summarizing the regional water-resources monitoring framework and the interrelations among steps 1 through 7 - continued.

It should be recognized that for some critical indicators that are less sensitive to change, the detection of change may not occur until effects from stressors have become widespread, for example, as in the case of contaminated off-site groundwater. These issues can not be addressed only by monitoring, and fall outside the scope of this framework. In this case, numerical modeling of the hydrologic system may be necessary to forecast these changes before widespread degradation occurs. This allows land managers the opportunity to implement additional best management practices or lease stipulations before a widespread problem is identified by monitoring data.

The specific objectives of Step 4 are:

1) Use the conceptual model developed in Step 3, in concert with understanding of the regulatory framework, the Resource Area Land-Use Plan, Land Health Standards, and Reasonable Foreseeable Development Plan, to identify indicators to be measured,
2) Identify available information to quantify the spatial and temporal variability of the indicator,
3) Identify gaps in the available information that will be addressed in the monitoring plan that is to be developed, and
4) Recognize that the choice of indicators should be re-evaluated as new information or new monitoring [or analytical] methods become available.

Step 5 – Estimate the sensitivity of the indicators to detect change, to guide final indicator choice, and monitoring design

Understanding the response of an indicator to a stressor is key to developing an effective monitoring plan. The sensitivity of an indicator to change, the stressor referred to herein, can be greatly affected by the natural variability in the hydrologic system, pointing to the need for characterizing baseline conditions of the indicator. It is important not to confuse the precision and accuracy of analytical methods used to quantify indicators with the sensitivity of an indicator to stressors or with natural variability. The analogy of "signal-to-noise ratio" applies to this situation. The indicator may be precisely measured, but if the natural variability is large, changes in the indicator related to the stressor may not be recognized. Thus, an effective indicator of energy-related impacts is a parameter that can be measured precisely, has small natural variability, and can be clearly linked to an energy-development stressor (e.g. benzene in ground water). This improves the probability of recognizing real change in an indicator and that the change is more likely associated with a change in stressors associated with energy development.

The sensitivity of an indicator to detect change will help to determine the spatial and temporal frequency of monitoring. An indicator with low natural temporal and spatial variability would require fewer sampling sites and less frequent sampling than an indicator with high natural variability. As an example, some regulated organic compounds associated with energy development, such as benzene or toluene, naturally occur at very low concentrations (if present at all) and have low natural variability. In contrast, some parameters that are influenced by both natural and anthropogenic variables, such as sediment yield, may have high natural variability. In the case of sediment yield, intensive spatial and temporal sampling may be needed to separate sediment yield resulting from energy development from sediment yield resulting from natural variables and other land uses.

In setting up the monitoring design it is important to keep in mind the fundamental questions that need to be answered. Questions such as "Is X greater than Y at location Z?" are relatively easy to answer; however they provide little in the way of management direction because no association between stressor and receptor is considered. Alternatively, questions such as "Is A causing X to be greater than Y at location Z?" provide much more meaningful answers; however the monitoring design and data interpretation are substantially more involved. The specific questions to be answered by monitoring need to be articulated at this point. In some cases sufficient historical data will be available from the area of interest which will allow for a comparison of historical and contemporary data. In cases where sufficient historical data are not available it may be necessary to conduct parallel monitoring in an area (a control site or watershed) where no development is anticipated to allow for a geographical comparison of data. A great deal of care must be used in setting up parallel monitoring. In both cases a substantial investment in data analysis and interpretation will need to be recognized up front.

The specific objectives of Step 5 are:

1) Using information developed in Step 4, rank indicators in terms of measurement precision and natural variability,
2) Determine the spatial and temporal intensity of monitoring for each indicator in the context of the regional conceptual model, the Reasonably Foreseeable Development Plan, and the specific questions that need to be answered by monitoring, and
3) When prudent, apply numerical models to forecast the effects of stressors on indicators.

Step 6 – Describe a process by which management can identify thresholds of change requiring a management response

Thresholds of change most commonly addressed by land-use managers are those based on the regulatory process. These include drinking-water standards, in-stream water-quality standards, administered water rights, and the BLM Land Health Standards. Thresholds need to be set at a level sufficiently conservative so that once required, timely management response will allow for mitigation such that regulatory limits are not exceeded (e.g. if the background level of X is 100±10 and the regulatory limit is 150, then an appropriate threshold may be 130). Where no regulatory standard exists, thresholds of change could be identified by trends and occurrences of parameters outside natural variability and baseline which have the potential to cause unacceptable impacts. Evaluating thresholds of change of an indicator could also take into account issues identified in the Land Use Plan, Reasonably Foreseeable Development Plan, and the long-term goals of the regulatory process.

The methods that will be used to ensure regular assessment of monitoring data and comparison of indicators to the thresholds should be defined at this step. This analysis and interpretation is necessary to allow for timely adaptive management to mitigate or remediate the effects of energy development.

The specific objectives of Step 6 are:

1) Identify the regulatory limits for indicators,
2) Define thresholds for the indicators, and
3) Define the process that will be used to ensure regular assessment and interpretation of monitoring data with comparison to thresholds.

Step 7 – Identify clear connections between the overall monitoring program and the management decision process

This step defines what management actions need to be taken if a threshold is exceeded. These steps should typically define a process rather than a “cut in stone” response. Effective land-use management is informed by the science derived from monitoring and assessment. Similarly, the monitoring process is improved by regular exchange of information with the management process. Feedback loops between management and the monitoring program are established by an ongoing process of data interpretation in the context of existing Land Health and regulatory standards. In cooperation with water-quality regulatory agencies (State, Tribes, and or EPA) this process should identify if any indicators of interest exceed established thresholds and determine which stressors are most likely responsible for exceedances.

If it is determined that thresholds have been exceeded and the responsible stressors have been identified, this would provide guidance to managers for evaluating energy-resource development to date and the effectiveness of existing best management practices and lease stipulations. This would allow managers to make adjustments to plans for mitigation, remediation, and future energy development. The monitoring program should inform plans for mitigation and remediation by providing timeframes for expected change.

The specific objectives for Step 7 are:

1) Define the process (e.g. coordination with regulatory agencies) that will be followed if thresholds are exceeded,
2) Through the ongoing process of data interpretation, use monitoring data to inform the management process,
3) Improve the monitoring process by regular exchange of information with the management process, this may require revisiting previous steps, and
4) Schedule management updates so that decisions are timely and based on the most current information.

In addition to the Regional Framework described in the following, a discussion of "Water Resources Monitoring Frameworks and Assessments" is included in Appendix 1.

Chapter 2

Implementation of the Regional Water-Resource Monitoring Framework: Examples for the White River Field Office, Meeker, Colorado

In this chapter, the seven-step monitoring framework described Chapter 1 is applied to the Piceance Creek watershed (417,280 acres) and the Yellow Creek watershed (167,680 acres) in the BLM White River Field Office (http://www.co.blm.gov/wrra) (Figure 2). The White River Field Office is located in Meeker, in northwest Colorado and incorporates parts of Rio Blanco, Moffat, and Garfield Counties. The Resource Area includes approximately 2,675,360 acres of BLM, National Forest, National Park, State, and privately owned and administered lands. Of this, the BLM administers approximately 1,455,900 surface acres, and 365,000 acres of mineral estate underlying state and privately owned surface estate.

Currently (2007) because of the increase in development of natural gas, the Resource Management Plan (RMP) for the White River Field Office (WRFO) is being revised. In the Piceance Creek and Yellow Creek watersheds (study area), energy exploration and development is expected to continue for the balance of the 21st century and beyond. Federal leases for research development and demonstration (RD&D) of oil shale have been let at five sites in the watersheds (Figure 3). The area contains enormous resources of oil shale (Taylor, 1987) which, depending on the outcome of the RD&D leasing and the price of oil, may lead to commercial development of the oil shale that underlies the study area. References in this chapter to the RMP are from the 1997 White River Record of Decision and Approved Resource Management Plan (BLM, 1997).

Step 1. Specify Monitoring Goals and Objectives

Monitoring goals and objectives should be governed by applicable planning documents, laws, and regulations developed by BLM, Tribes, State, and local entities. For the BLM WRFO the RMP, Standards for Public Land Health in Colorado (BLM, 1996), and the Environmental Assessments (EAs) for the RD&D oil shale leases (http://www.co.blm.gov/wrra/nepa.htm) provide perspective on goals and objectives for the monitoring framework. In addition to these documents, results from the July 2006 scoping meeting at the White River Field Office (table 1) provide further direction for specifying monitoring goals and objectives. The meeting was attended by about 35 representatives from BLM, Colorado Division of Wildlife, The Nature Conservancy, and USGS. This was the initial meeting to identify issues related to the potential effects of energy development on water resources in the White River Field Office. Instream water-quality standards for physical properties and biological indicators, inorganic constituents, and metals are set for water bodies in Colorado by the Colorado Water Quality Control Commission (http://www.cdphe.state.co.us/op/wqcc/index.html) and implemented and managed by the Water Quality Control Division of the Colorado Department of Public Health and Environment (http://www.cdphe.state.co.us/wq/). The Colorado Water Quality Control Commission has adopted standards to regulate ground-water quality. Also, in cooperation with the Colorado River Salinity Control Act (Public Law 92-500), the State of Colorado participates by regulating the discharge of salt (one ton per acre foot) into Colorado streams and rivers in the Colorado River Basin. In addition, the BLM participates with the Colorado River Salinity Control Forum (http://www.usbr.gov/uc/progact/salinity/) and has significant responsibilities for controlling salinity loading from lands that BLM administers in the Colorado River Basin. The BLM role in the Salinity Control Forum is stated in Public Law 98-569 (1984 Amendment to the Salinity Control Act), which directed the Secretary of Interior to develop a comprehensive program for minimizing salt contributions from lands administered by the Bureau of Land Management (Heidi Hadley, written comm. BLM Salinity Coordinator Salt Lake City, Utah). Finally, the Colorado Division of Water Resources (DWR, http://water.state.co.us/) administers water rights on water bodies in Colorado. Issues of ground-water and stream depletion related to the injury to water rights would be best defined by DWR.

The BLM documents, July 2006 meeting summary, Salinity Control Act, instream and ground-water-quality standards promulgated by the State of Colorado Water Quality Commission, and administration of streams and rivers by the Colorado DWR provide the context for defining issues and the eventual identification of monitoring goals and objectives. For example, the Approved Resource Management Plan (1997, p. 2-2) for the WRFO identifies an objective for surface water to “Maintain and improve water quality and quantity in order to be compatible with existing and anticipated uses, to comply with applicable state and federal water quality standards, and to meet the goals in Standard Five of the Standards for Public Land Health.” Similarly, for ground water, the objective (p. 2-3) is to “Ensure that the quantity and quality of aquifer system integrity is maintained and the goals in Standard Five of the Standards for Public Land Health are met.”

Standards for Public Land Health in Colorado, November 1996

STANDARD 5: The water quality of all water bodies, including ground water where applicable, located on or influenced by BLM lands will achieve or exceed the Water Quality Standards established by the State of Colorado. Water Quality Standards for surface and ground waters include the designated beneficial uses, numeric criteria, narrative criteria, and antidegradation requirements set forth under State law as found in (5 CCR 1002-8), as required by Section 303(c) of the Clean Water Act.

> Indicators:
> Appropriate populations of macroinvertebrates, vertebrates, and algae are present.
> Surface and ground waters only contain substances (e.g. sediment, scum, floating debris, odor, heavy metal precipitates on channel substrate) attributable to humans within the amounts, concentrations, or combinations as directed by the Water Quality Standards established by the State of Colorado (5 CCR 1002-8).

Another example of a monitoring goal and objective regarding water resources in the WRFO is found on page 2-36 of the RMP where “BLM authorized land uses that adversely affect long-term riparian, channel, or aquatic conditions associated with Colorado River cutthroat trout fisheries will be prohibited.” The final example in the RMP of a monitoring goal and objective, presented here, regards water rights and water depletions (p. 2-3 and 2-4). Adequate water rights are to be secured to support public resource programs and to ensure that BLM administered projects are in compliance with the U.S. Fish and Wildlife Service (USFWS) Programmatic Biological Opinion (PBO) for water depletions in the Colorado River Basin. A summary of example goals and objectives for monitoring water resources outlined in the RMP, Standards for Public Land Health, and the FONSI from the EA for the Shell RD&D tract will help to identify monitoring goals and objectives. These goals and objectives can be cross referenced with issues identified in table 1 to connect goals and objectives identified in BLM guidance documents. Additional information regarding how to frame water-resources issues is included in the section “Water Resources Monitoring Framework and Assessments” Appendix I .

Summary of Goals and Objectives:

A. Maintain and improve water quality
B. Comply with applicable state and Federal water-quality standards
C. Ensure quantity and quality of aquifer system integrity
D. Exclude BLM authorized land uses that might adversely effect Colorado River cutthroat trout
E. Secure adequate water rights to support public resources programs
F. Ensure that BLM projects comply with USFWS PBO for water depletions
G. Develop detailed water-resource monitoring network in association with oil shale RD&D lease tracts and natural gas leases

A review of the issues outlined in table 1 provides some context for the Goals and Objectives listed above. Steps 2-4 in the following sections will characterize anthropogenic stressors, develop regional questions and conceptual models that link stressors and receptors, and identify indicators to measure the effects of stressors on receptors. The discussion and actions identified in steps 2-4 will address the Goals and Objectives that were derived from BLM documents and applicable state and Federal regulations.

Step 2. Characterize anthropogenic stressors that may affect receptors and parameters of interest

Leasing for the extraction of natural gas has been ongoing for decades in the WRFO. In 2006 with the advent of improved down-hole fracking techniques in tight-gas formations and the construction of a network of regional pipelines to transport the gas to market, development of natural-gas resources in the WRFO is occurring at an accelerated pace. Five RD&D oil shale tracts were leased in the Piceance and Yellow Creek watersheds in 2006 (Figure 3). These 160 acre areas have been leased to provide opportunity for the development of economically feasible and environmentally acceptable methods for extracting oil from shale. If the RD&D process is successful, commercial leasing is expected that would potentially impact thousands of acres of BLM land in the Piceance and Yellow Creek watersheds. Although coals are present in the basin the extent to which the development of coal-bed methane will occur is unknown.

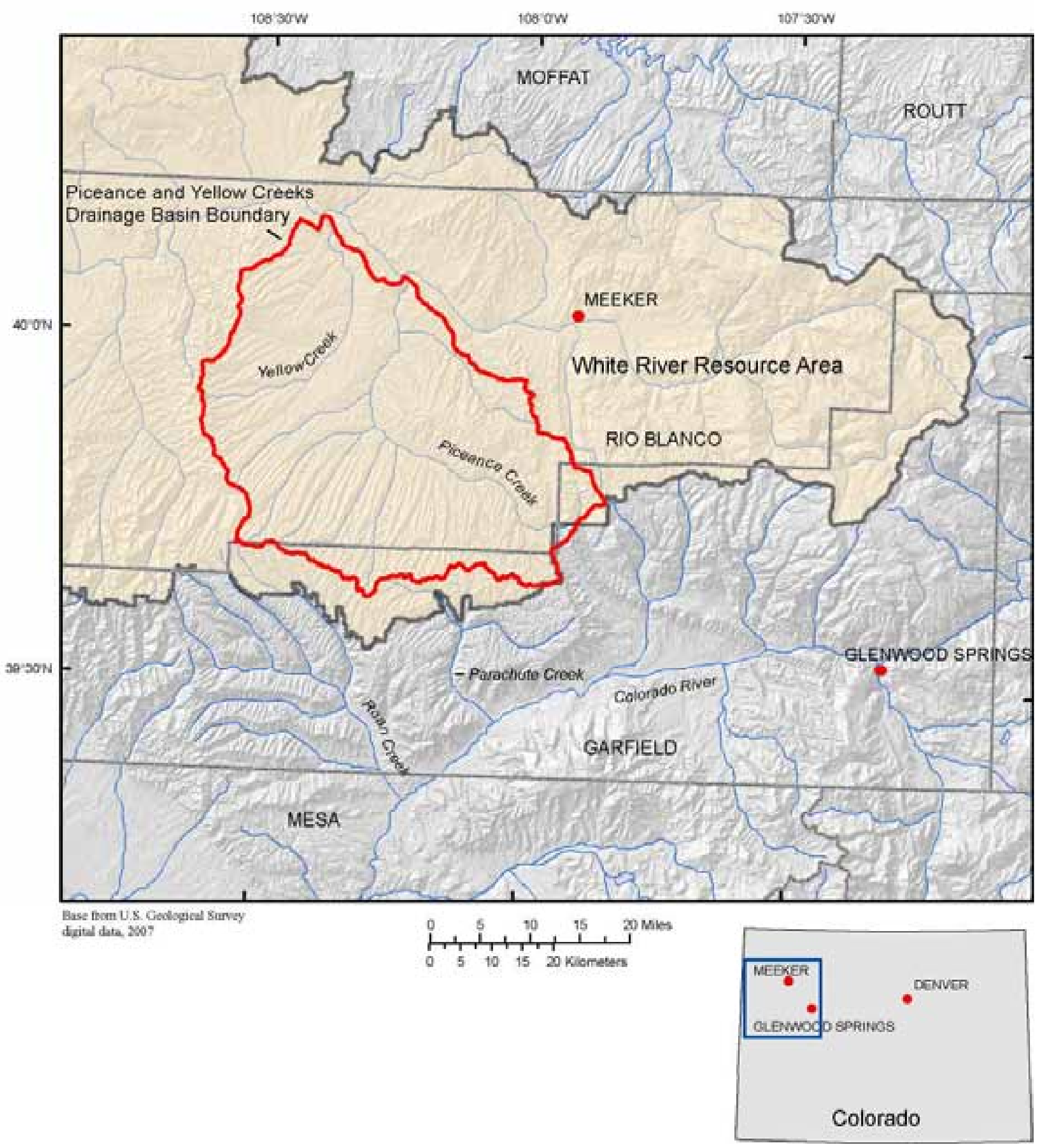
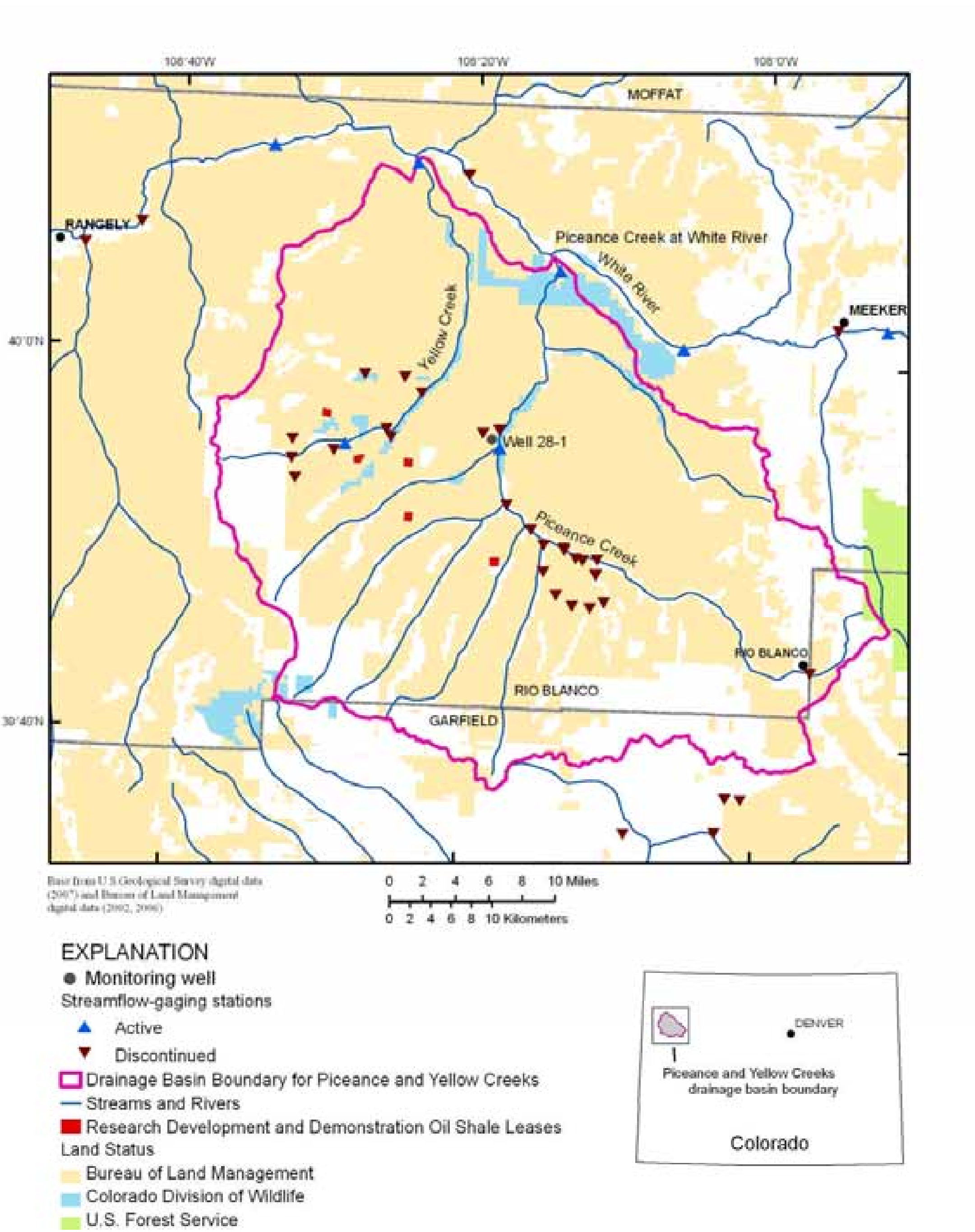


Figure 2. Location of the White River Field Office, in Meeker, and Piceance Creek and Yellow Creek watersheds.



Base from U.S. Geological Survey digital data (2007) and Bureau of Land Management digital data (2002, 2006)

Figure 3. Location of research development and demonstration oil-shale lease tracts, active and inactive streamflow-gaging stations, and a monitoring well in the Piceance Creek and Yellow Creek watersheds.

Table 1. Issues identified during July 2006 scoping meeting.

Issues related to land-management
What is the context for evaluating changes (both anthropogenic and natural)?
What are the implications of landscapes changes to water quantity, quality, and watershed function?
What are the indirect and indirect effects over time of energy development at local and regional scales?
How can changes to water quality and quantity be evaluated (identify surrogates)?
How to determine BMP effectiveness?
How do we implement performance based mitigation and monitoring?
How can the threshold of acceptable change be defined? How to quantify effects on water-quality standards violated or beneficial uses?
Issues related to tracking surface disturbance
How to address the progression of surface disturbance?
At what point do we determine what information is needed for what purpose?
What are the important environmental factors to consider in siting new gas wells?
What information is needed to track surface disturbance?
What environmental factors need to be considered in locating new energy development?
Issues related to involvement with state and other federal agencies
State agencies are critical to the process – Sampling sites operated – Personnel involved – How does the monitoring plan support the states responsibilities under the Clean Water Act? Acknowledge BLM MOU with states to minimize NPS pollution.
Will Section 7 consultation focus the depletion and produced waters issues for depletion thresholds for T&E fish?
Issues related to characterizing baseline conditions and anthropogenic effects
How to differentiate natural variability related to climate, geology, and other factors from industry effects?
Characterize the type of oil and gas development, e.g. conventional/oil shale/CBM and develop a monitoring framework to address the differences in development.
Issues related to tracking effects on ground water
Will development of oil and gas wells and oil shale have the potential to affect aquifers?
Is there a hydrologic connection between affected units and used aquifers?
How does re-injection ultimately affect other aquifers?
How does fracturing potentially affect flow in and between aquifers?
How does overspray or leakage from retention ponds affect shallow ground water?
Issues related to tracking effects on ground-water surface-water interactions
Does the development of oil and gas have the potential to effect base flow of springs and streams?
How can small isolated springs that support intermittent stream flows be protected?
What will be the residual effects of retorting oil shale on surface and ground water quality?
How can effects to spring flow and water quality be monitored at site and regional scales?
Issues related to tracking effects on surface water
How can effects of flow modification and water quality alteration on aquatic habitat best be measured?
At what level of impacts do we reach impairment of beneficial uses?
How can sediment and salinity best be monitored to quantify energy impacts? - At what level of impacts do we reach impairment of beneficial uses? How can impacts to stream morphology and stream stability best be measured? - At what level of impacts do we reach impairment of beneficial uses? Will water be imported to the Piceance area and what will be the effects?
How can the source of impairment to beneficial use be identified?
What are the cumulative effects of surface disturbance in a watershed on sediment, salinity and stream biology?
How should the results be compared to aquatic endpoints?
How should stream sediments be measured? - How should the results be compared to the state of Colorado narrative sediment standards?

Energy development is anticipated to cause short-term and long-term surface disturbance. Short-term effects may result from the initial construction of well pads, drilling reserve pits, access roads, and access corridors (pipelines). Assuming adequate interim reclamation of well pads, long-term effects are generally associated with the maintenance of access roads and other access corridors. Effects of surface disturbance are considered to be cumulative and generally are:

- increased hillslope and surface-erosion rates resulting in increased sediment loading and an increase in associated water-quality constituents (salinity, nutrients, and metals) in receiving streams,
- increased surface-water runoff volume and frequency, and
- surface spills of industrial chemicals.

Subsurface effects of energy development may include:

- contamination of ground water with drilling fluids,
- chemical spills or leakage from drilling reserve pits resulting from the drilling and well-fracking process,
- dewatering of aquifers at various depth,
- changes in the groundwater- to surface water exchange (discharge/recharge), and
- depressurization of aquifers resulting in alteration of local and regional ground-water flow systems.

We will use the goals and objectives identified in step 1 as a template to identify stressors from energy development (table 2). Statements of hydrologic concern will be developed for identified stressors, and will be developed further in Step 3.

In Step 2, potential stressors associated with energy development in the White River Field Office (WRFO) were identified. Step 3 focuses on understanding how and through what pathways those stressors could affect receptors by developing specific regional questions and conceptual models of the hydrologic system. Two key outcomes of this assessment are: (1) Hydrologic concern statements for each stressor-receptor pair (qualitatively similar to a risk assessment) and (2) A list of indicators that can be measured to quantify the effect of stressors on receptors. Figure 4 illustrates the progression of thought from establishment of a goal to the identification of an indicator.

To illustrate the process for ground-water resources, we will focus on the stressor ground-water pumping (dewatering) during gas and oil-shale development. For surface-water resources, we will focus on the stressors effects of changes in the chemistry of ground-water contributions and the effect of the surface disturbance on salinity loading to Piceance Creek, Yellow Creek, and the White River. Keep in mind that similar processes would be applied to each stressor identified in Step 2 (tables 2 and 3).

Table 2. Goals and related stressors for surface water and ground water.

Goals Identified in Step 1	Stressor Related to Surface Disturbance	Stressor Related to Subsurface Disturbance
Maintain and improve surface-water quality and comply with applicable state and Federal water-quality standards	Road and pipeline construction, accidental spills, Leakage from drilling reserve pits	Improperly sealed well casings, in situ heating of oil-shale
Ensure quantity and quality of aquifer system integrity	Accidental spills, leakage from drilling reserve pits	Aquifer dewatering, improperly sealed well casings, in situ heating of oil shale
Exclude BLM authorized land uses that might adversely affect Colorado River cutthroat trout	Changes in channel morphology, accelerated sediment deposition, changes in water temperature	Aquifer dewatering
Secure adequate water rights to support public resources programs and ensure that BLM projects comply with USFWS PBO for water depletions	Increased consumptive use of surface waters	Aquifer dewatering, alteration to recharge areas
Develop detailed water-resource monitoring network in association with Oil Shale RD&D lease tracts	Not applicable	Not applicable

Table 3. List of selected stressors and possible receptors.

Stressor	Possible Receptor
Road construction	Trout, surface-water quality
Aquifer dewatering	Water quantity in water-supply wells, springs, and streams
Accidental spills, leakage from reserve pit	Ground-water and surface-water quality
In situ heating of oil shale	Ground-water and surface-water quality
Alteration to recharge areas	Water quantity in water-supply wells, springs, and streams
Increased consumptive use of surface waters	Surface-water quantity and quality

Step 3 – Develop specific regional questions and conceptual models to describe how processes and pathways anthropogenic stressors affect receptors

Ground-Water Resources

Gas and oil-shale development will necessitate ground-water pumping because water is naturally co-produced in varying amounts with gas and because *in situ* heating of oil shale requires dewatering of the heated interval. Thus, development of both energy resources will result in reduced formation fluid pressures that could lower ground-water levels, alter ground-water flow directions, and reduce ground-water discharge to important receptors. The primary receptors for ground water in the WRFO are water-supply wells for industry, irrigation, and human uses, and surface-water bodies such as springs and streams. The extent to which ground-water pumping affects those receptors will depend on a combination of factors that include locations of the stressors relative to receptors, magnitude of pumping, and hydrologic characteristics of the regional flow system. Conceptual models can be used to qualitatively integrate these factors with other existing knowledge of the flow system, including water-quality data for ground water and surface water (Taylor, 1987; Ortiz, 2002), to develop and address questions about ground-water-pumping effects on water-levels and discharge to springs and streams.

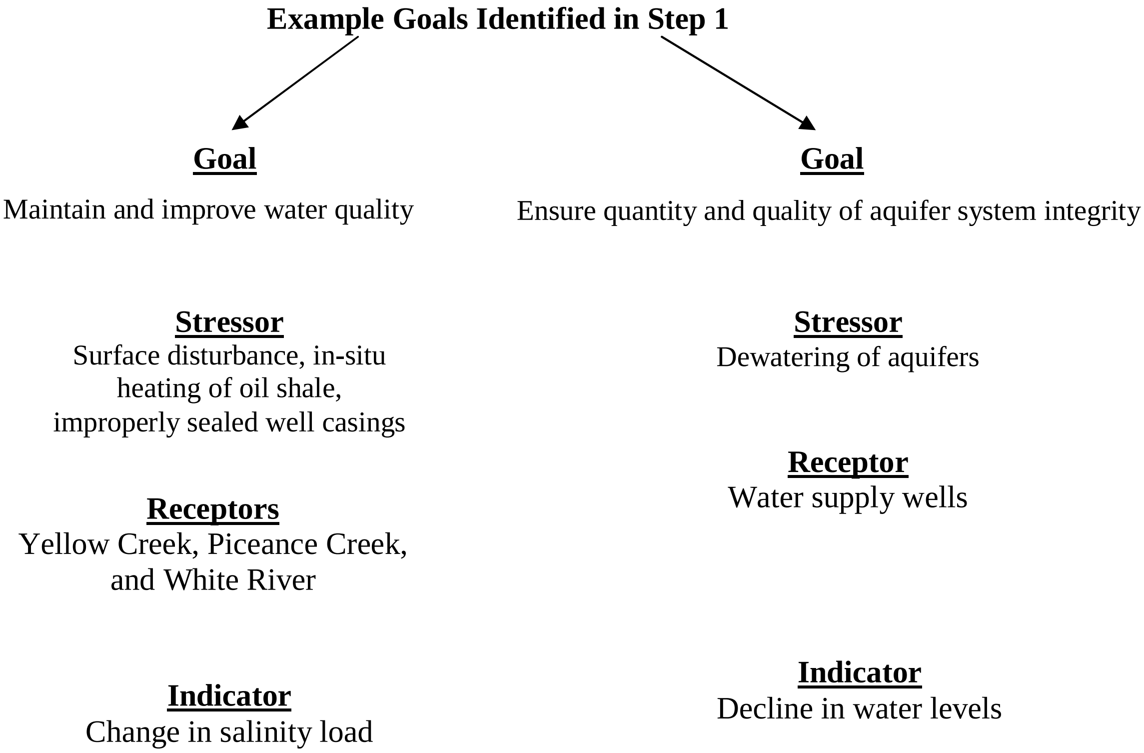


Figure 4. Example of concept development relating goals, stressors, receptors, and indicators.

A conceptual model of the regional ground-water flow system in the WRFO can be developed using existing data from studies done by the USGS and other agencies during the 1970s and 1980s, from studies done more recently by industry and reported to BLM, and from records maintained by BLM and other governmental agencies. For the purpose of this example, a modified version of the conceptual model of ground-water flow developed by Taylor (1987) will be used (Figures 5 and 6).

According to this conceptual model, there are two important aquifer systems in the basin: the alluvial aquifer system and the bedrock aquifer system. The bedrock aquifer system is further subdivided into upper and lower aquifers that are separated by a confining unit in the oil-shale bearing zone of the Green River Formation.

Ground-water recharge occurs primarily in the uplands on the eastern, western, and southern margins of the basin. Recharge moves through the upper and lower bedrock aquifers and discharges to the alluvial aquifers in the valleys.

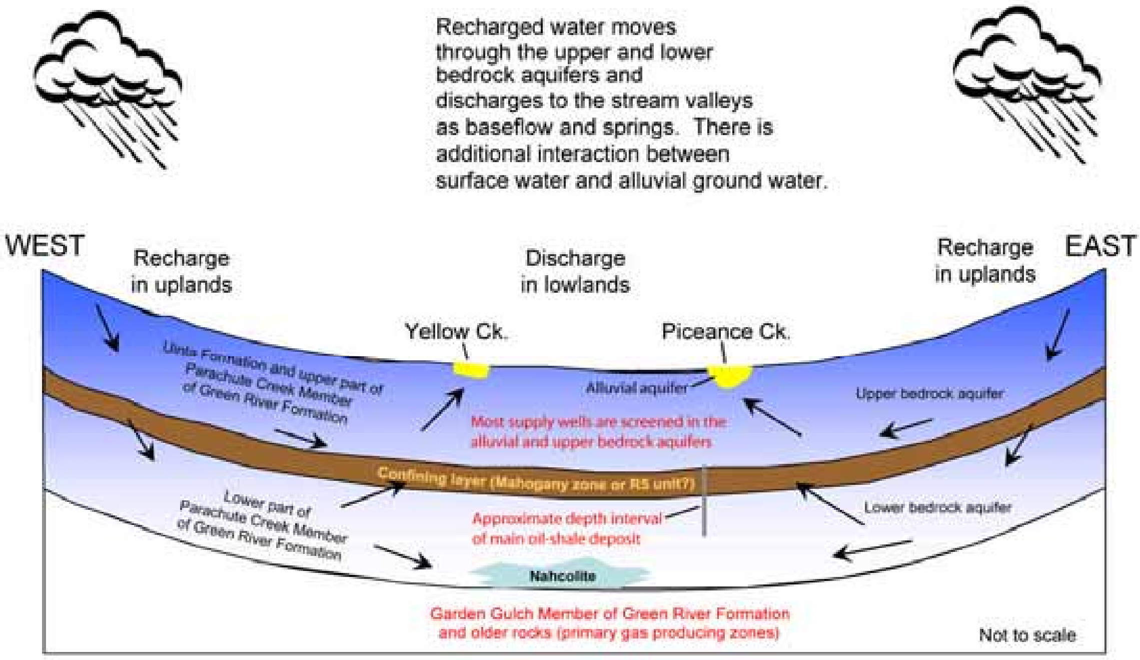


Figure 5. Diagrammatic east-west section of the hydrologic system (modified from Taylor, 1987). Depth to the top of the Garden Gulch Member of the Green River Formation in the basin center may be at least 2,000 feet below land surface (Welder and Saulnier, 1978). Taylor (1987) proposed that the Mahogany zone was the primary confining layer between the upper and lower bedrock aquifers. Thickness of the Mahogany zone may be 150 to 300 feet (Welder and Saulnier, 1978). More recent data collected by Shell Frontier Oil and Gas indicates that the R5 unit, which is deeper and possibly thinner than the Mahogany zone, is the primary confining layer.

Figure 5. Diagrammatic east-west section of the hydrologic system.

Most supply wells are screened in the alluvial aquifer or in the upper bedrock aquifer. Most natural gas production will occur in formations much deeper than the base of the lower bedrock aquifer. The primary oil-shale zone extends from the base of the upper bedrock aquifer into the lower bedrock aquifer. Detailed information on the location and magnitude of ground-water pumping for energy development is available from lease records maintained by BLM, from data reported to the Colorado Oil and Gas Conservation Commission in the case of natural gas, and from data reported to the Colorado Division of Reclamation Mining and Safety in the case of oil shale. Detailed information on locations of industrial, irrigation, and drinking-water wells is available from the Colorado Division of Water Resources and some information on spring locations may be available from the Colorado Division of Wildlife and the USGS Ground-Water Site Inventory (GWSI) database. It is important to remember that the conceptual models should be refined as new information from these and other sources becomes available. Moreover, the conceptual models should be used to identify data gaps in the available information that will be addressed in the monitoring plan that is to be developed.

From the list of stressors developed in table 2, a list of potential receptors can be identified (table 3). Once receptors are identified then the conceptual models can be used to describe how, and through what pathways, anthropogenic stressors affect receptors. In Step 3 to follow, we will describe two examples of the process of linking stressors and receptors - one to describe the effects of anthropogenic stressors on a ground-water receptor and another for a surface-water receptor

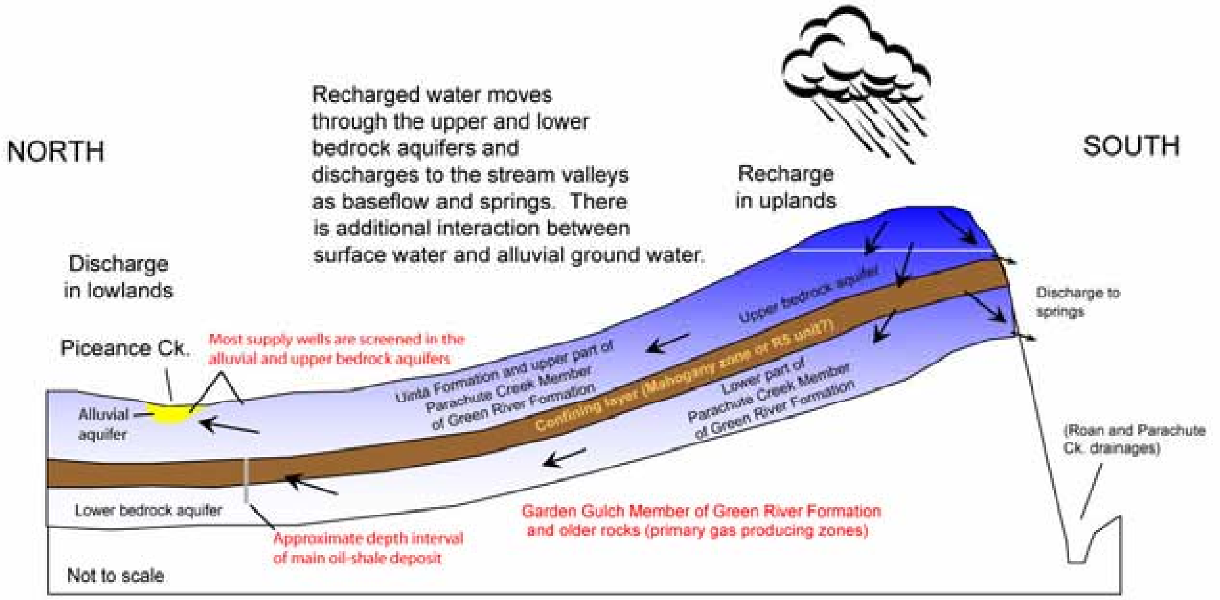


Figure 6. Diagrammatic north-south section of the hydrologic system (modified from Taylor, 1987). Depth to the top of the Garden Gulch Member of the Green River Formation in the basin center may be at least 2,000 feet below land surface (Welder and Saulnier, 1978). Taylor (1987) proposed that the Mahogany zone was the primary confining layer between the upper and lower bedrock aquifers. Thickness of the Mahogany zone may be 150 to 300 feet (Welder and Saulnier, 1978). More recent data collected by Shell Frontier Oil and Gas indicates that the R5 unit, which is deeper and possibly thinner than the Mahogany zone, is the primary confining layer.

Figure 6. Diagrammatic north-south section of the hydrologic system.

Some key questions that result from the conceptual model of stressors (pumping), receptors (wells, springs, streams), and regional hydrology includes:

- Will ground-water pumping related to gas and oil-shale development lower water levels in supply wells on a regional basis?
- Will ground-water pumping related to gas and oil-shale development reduce spring discharge or baseflow to streams on a regional basis?
- Do the effects of pumping have the potential to affect water supplies or aquatic life on a regional basis?
- Will ground-water pumping cause land subsidence on a regional basis?

The following “Hydrologic Concern Statements” related to these questions are presented based on the preliminary conceptual model of flow and pumping (Figures 5 and 6). Based on these conceptual models, ground-water pumping during natural gas production is *unlikely to cause noticeable impacts* on water levels in the alluvial and upper bedrock aquifers where most supply wells are located, or on spring discharge and stream baseflow. This is because most gas-producing zones in the WRFO are located in geologic formations that are much deeper than the Uinta and Green River Formations and because of the presence of confining layers such as the R5 unit that hydraulically separate the shallow aquifers from the gas-producing intervals. Nevertheless, because extensive gas development is anticipated during the next 20 years (perhaps more than 15,000 new gas wells), and because our current understanding of the hydraulic properties of each formation is limited, it would be prudent to collect data in key locations to validate this assumption. If the gas-producing intervals are not hydraulically well confined, then the effects of regional depressurization in those intervals could cause noticeable impacts on water levels in the shallower aquifers. Note that this qualitative analysis does not consider the possible effects of produced-water leakage from holding ponds at the land surface on the ground-water system. That is a separate stressor that would require its own analysis.

Ground-water pumping during oil-shale development *is likely to cause noticeable impacts* on water levels in the bedrock aquifers at the research-lease scale (160 acres), but it has low potential for unacceptable impacts at the regional scale. Pumping at the research-lease scale *is not likely to cause noticeable impacts* on water levels in the alluvial aquifers at the regional scale. This is primarily because of the small area of development. Data collected during the oil-shale research and development phase will help to determine whether pumping during the commercial phase of development (~5000-acre leases) will have the potential to cause unacceptable impacts on water levels, spring discharge, and stream baseflow at the regional scale. Consultation with experts on land subsidence will be needed to determine whether pumping would cause noticeable or harmful land subsidence in the WRFO.

Surface-Water Resources

Subsurface activities related to energy development may affect rates of salt dissolution in ground water and ground-water/surface-water interactions that contribute salinity to area streams. Additionally, surface disruption resulting from drilling of wells, and construction of pipelines and roads for both gas and oil-shale development may increase sediment yields, resulting in increases in salt loading to area streams and rivers and possibly changes in streambed characteristics from sedimentation. The receptors of the effects of these stressors will be Piceance Creek, Yellow Creek, and subsequently the White River. The extent to which rates of salt dissolution in ground water, changes in ground-water contributions to streamflow, and increased sediment yields will effect salinity and bed characteristics in streams and rivers depends on a combination of factors that includes: locations of the stressors relative to receptors including the extent of subsurface disruption that results in increased salt dissolution rates; ground-water pumping and reinjection of pumped groundwater; extent of surface disturbance (surface disruption and evaporation ponds); effectiveness of efforts by land managers to remediate surface disturbance; hydrologic characteristics of the regional flow system, and the sediment-transport capacity of streams. Conceptual models can be used to qualitatively integrate these factors with other existing knowledge of the flow system to develop and address questions about the effects of energy development activities on salinity in area creeks and rivers.

A conceptual model of the regional salinity in creeks and rivers in the WRFO can be developed using existing data from studies done by the USGS and other agencies during the past 30 years, from studies done more recently by the energy industry and reported to BLM, and from records maintained by BLM and other governmental agencies. For the purpose of this example, results from Weeks and others (1974), Frickel and others (1975), Robson and Sauliner (1981), Warner and others (1985), Tobin (1993), and Ortiz (2002) are used to develop the conceptual model of salinity in creeks and rivers in the study area.

According to this conceptual model, salt concentrations and loads in the White River, Piceance Creek, and Yellow Creek increase in a downstream direction (Weeks and others, 1974 and Tobin, 1993). Robson and Sauliner (1981) estimated that 80 percent of the annual streamflow in Piceance Creek occurs during base-streamflow conditions with discharge from springs being an important contributor to streamflow during this period. Tobin (in Taylor 1987) and Ortiz (2002) measured an increase in streamflow in Piceance Creek during the base-streamflow period (Figure 7). During this period of streamflow measurement, it was observed that the Dry Fork of Piceance Creek was the only tributary contributing streamflow to Piceance Creek. Inclusion of the conceptual model presented for groundwater is needed to understand the affect of aquifer systems in the basin on salt contributions to streams.

The bedrock aquifer system is subdivided into upper and lower aquifers that are separated by a confining unit in the oil-shale bearing zone of the Green River Formation. Ground-water recharge occurs primarily in the uplands on the eastern, western, and southern margins of the basin. Recharge moves through the upper and lower bedrock aquifers and discharges to the alluvial aquifers in the valleys.

Discharge of ground water from alluvial valleys and where streams intersect bedrock aquifers contribute to salinity loading. Increased sediment yield rates would accelerate the transport of salt to area creeks and streams. Sediment yields were characterized in the Piceance Basin by Frickel and others (1975). It was estimated that sediment yields from areas of surface disturbance would be 50 to 90 percent greater than for undisturbed areas or areas where surface disturbance was remediated. Analysis of the effects of increased sediment yields on salt loading is not available. However, Vaill and Butler (1999) reported that most sites available for trend analysis in Piceance Creek had decreasing trends in salinity loading, while sites on Yellow Creek varied between no trend to an increasing trend. For the sites on the White River that bracket the inflows of Piceance Creek and Yellow Creek there were decreasing trends in salt loading.

Some key questions that result from the conceptual model of stressors (road construction, in situ heating of oil shale, and improperly sealed well casings), receptors (creeks and rivers), and regional hydrology includes:

- Will subsurface disturbance related to gas and oil-shale development increase rates of salt dissolution in groundwater on a regional basis?
- Will subsurface disturbance related to gas and oil-shale development decrease spring discharge and ground-water discharge that supports baseflow to streams on a regional basis?
- Will surface disturbance increase sediment yield and salt loading to streams on a regional basis?
- What other receptors may be affected by the effects of increased sediment yields?

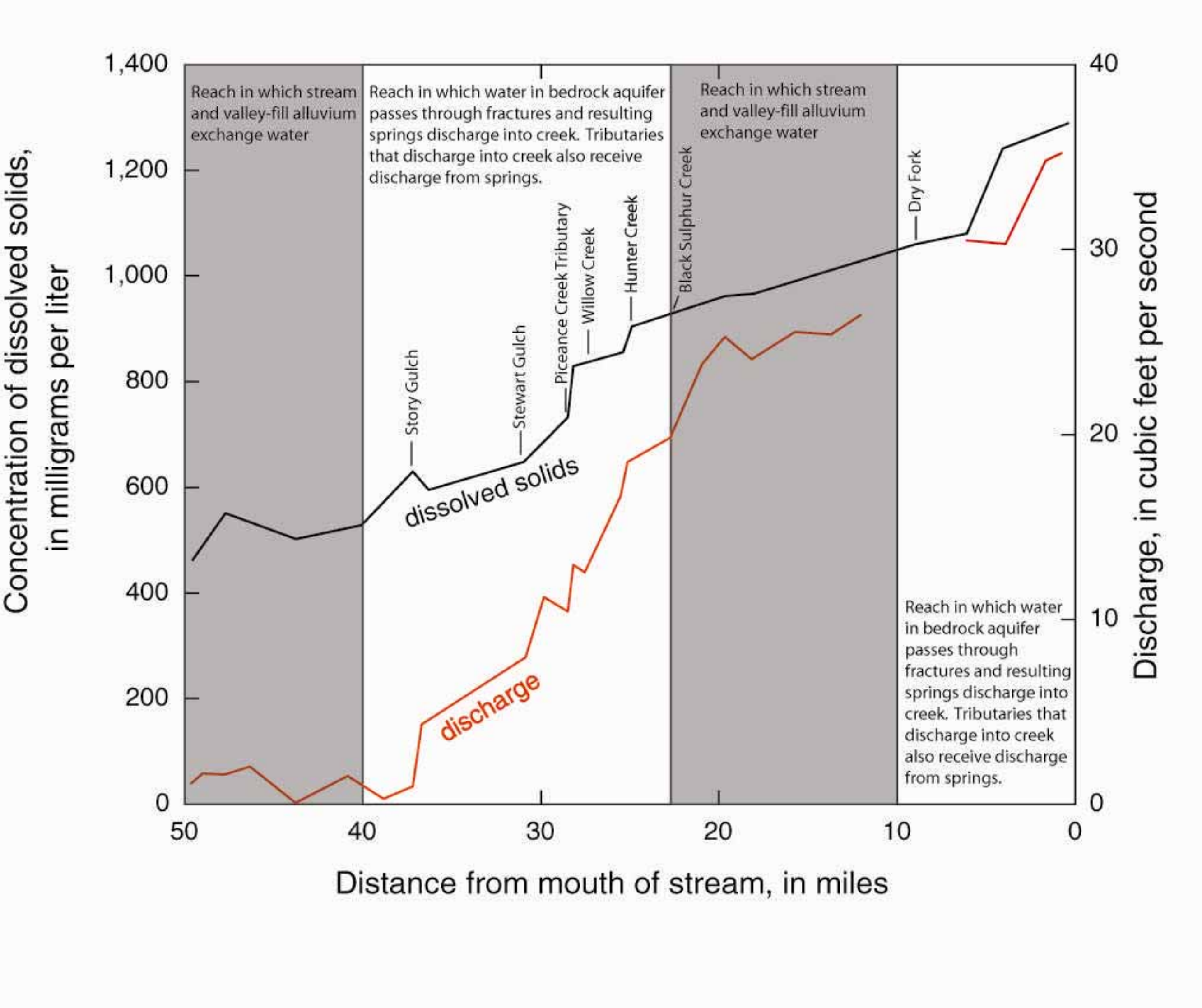


Figure 7. Profiles of streamflow and selected major ions for Piceance Creek (Tobin in Taylor, 1987).

The following “Hydrologic Concern Statements” related to these questions are presented based on the preliminary conceptual model of subsurface and surface salinity sources (loading) and transport. The two types of disturbance, subsurface and surface, are expected to accumulate effects at different rates and at different times in the energy-development scenario. The cumulative effects of subsurface disturbance will occur over the next 50 to 100 years. Currently, 2007, the dewatering and depressurization of aquifers resulting from the development of natural gas is occurring at depths below the oil shale deposits of the Green River Formation and in the short term are *unlikely to cause noticeable impacts*. It is anticipated that the “gas play” in the Piceance Basin will occur at a steady pace and be mostly developed over the next 50 years. Additionally, there are plans for commercial oil-shale leasing awaiting the completion of the Programmatic Environmental Impact Statement. During that time, oil-shale development is expected to unfold into producing 500,000 to 2 million barrels of oil per day. It is anticipated that long-term development using in situ heating of oil shale *is likely to cause noticeable impacts* regarding rates of salt dissolution in groundwater on a regional basis.

Surface disturbance from energy development is presently occurring on a landscape that has primarily been used as wildlife habitat and agricultural activity, (irrigated hay meadows adjacent to Piceance Creek and the White River, and livestock since the latter part of the 19th century). The development of gas-well pads, and drilling reserve pits, along with expansion of the network of roads and pipelines servicing those sites has been well underway since the late 1990s. Except for expected natural variability, the stressors that affect salt loading between ground-water and surface-water sources in creeks and streams of the study area have been relatively undisturbed for the past 125 years. With the advent of increased surface disturbance from expansion of the current gas play in the study area it *is likely to cause noticeable impacts* on sediment yields and subsequent salt loading to streams on a regional basis.

In addition to possibly increasing salinity loading in streams, increases in sediment yield that may result from surface disturbance may also affect stream stability and aquatic habitat in creeks and rivers in the study area. Increased sedimentation of creeks and streams is addressed by the goals and objectives “Maintain and improve water quality” and “Comply with applicable state and Federal water-quality standards.” A process for addressing the effects of energy development (primarily surface disturbance) on stream biology can be found in the section “Stream Biology Resource Monitoring Related to Energy Development” in Appendix 1.

Step 4 – Suggest indicators to measure the effects of anthropogenic stressors and define existing information availability and needs

In Step 4, a list of indicators is developed that can be measured to quantify the effect of stressors on receptors. This process requires an understanding of the existing information and should entail assembling data from disparate sources (industry, local, state, and Federal agencies), identifying ongoing data streams from many sources (currently most data collection in the study area is being collected by industry), and maintaining data collected in some accessible format that is regularly updated. Currently in the study area there is no local, state level, or national database that provides a uniform comprehensive database for surface-water and ground-water data. For the purposes of developing a robust and cost-effective monitoring plan, a compilation and analysis of available data is needed and would benefit from the following:

- Evaluate existing water-resources data for uniformity.
- Develop a web-accessible common data repository that provides energy operators, researchers, consultants, agencies, and interested stakeholders equal access to the latest information.
- Perform and publish a baseline assessment of available water-resources data.
- Use this information to inform regional monitoring strategies to more economically fill identified data gaps by reducing duplication of effort while still meeting regulatory requirements.
- Examples of comprehensive websites and data repositories are:
  South Florida Information Access: http://sofia.usgs.gov/index.html
  USGS Monterey Bay Science: http://montereybay.usgs.gov/
  Water Quality of San Francisco Bay: http://sfbay.wr.usgs.gov/access/wqdata/
  High Plains Regional GW Study: http://co.water.usgs.gov/nawqa/hpgw/HPGW_home.html
  Comprehensive Data Catalog sites: http://catalog4.usgs.umr.edu/site/csc/index.html
  Eagle River Watershed Water Quality Database: http://co.water.usgs.gov/cf/eaglecf/default.cfm
  Ground-Water Ambient Monitoring and Assessment: http://ca.water.usgs.gov/gama/

Ground-Water Resources

The most effective indicators for the stressor-receptor example presented for ground-water resources in Step 3 are water-level measurements (supply-well receptor) and discharge measurements (spring and stream receptors). The following is a preliminary evaluation of data needs, availability, and gaps for these indicators:

- Long-term water-level measurements are needed at key locations in each aquifer to distinguish between natural variability in water levels and change related to pumping. [More on the sensitivity of indicators to detect change and on sampling design is discussed in Step 5.] Periodic water-level measurements were made in about 24 test wells by the USGS from about 1975 to 1982 (Welder and Sauliner, 1978). Shell Frontier Oil and Gas, Inc., Solvey Chemical Inc., and other companies currently (2007) may be making water-level measurements in a few locations (Figures 3 and 8), but those efforts are not regional in scope and the data are not always publicly available. It appears that the existing data are not adequate for establishing baselines and characterizing natural variability in water levels on a regional basis; therefore, a monitoring plan is needed to fill these gaps in available information.
- Potentiometric-surface maps are needed to determine directions of ground-water flow in each aquifer, to link stressors and receptors in the hydrologic system, and to place long-term water-level measurements made at key well locations in regional context. To the best of our knowledge, the most recent regional potentiometric-surface maps are those made by the USGS in the early 1980s (Robson and Saulnier, 1981). New data should be collected to update the regional potentiometric surface maps.
- Long-term discharge data are needed for springs in key locations to distinguish between natural variability in discharge and change related to pumping. To the best of our knowledge, long-term spring discharge data do not exist for the WRFO; therefore, a monitoring plan is needed to fill these gaps in available information.
- Long-term streamflow data are needed for streams potentially affected by subsurface and surface disturbances. The best long-term stream-discharge data are those for Corral Gulch near Rangely (33 years), Yellow Creek near White River (about 35 years of data), Piceance Creek below Ryan Gulch (40 years), and Piceance Creek at White River (about 43 years of data) (Figures 3 and 9). Those long-term records should be useful for separating natural variability in stream discharge from anthropogenic impacts at those locations. Additional stream gages will be needed to understand regional impacts of ground-water pumping on stream discharge.

Surface-Water Resources

The most effective indicators for the stressor-receptor example presented for surface-water resources in Step 3 are of salinity and discharge measurements (spring and stream receptors). The following is a preliminary evaluation of data needs, availability, and gaps for these indicators:

- Information needs discussed in Step 3 in the section on “Ground-Water Resources” will be needed to relate subsurface disturbance to the stressor-receptor example identified for addressing the goal to maintain and improve water quality. In particular, long-term discharge and water-quality data are needed for springs in key locations to monitor trends in salinity from ground-water sources.
- Long-term streamflow and water-quality data are needed at a network of surface-water sites for characterizing historic and baseline (current) conditions. These data are needed long-term for periodic trend analysis. Table 4 is a summary of selected historic and active streamflow-gaging stations and water-quality sampling sites on the White River, Piceance

Creek, and Yellow Creek. Other data is likely available from various state agencies like CDPHE, DRMS, and COGCC and industry.

Streamflow data are needed to perform flow adjustment of salinity data before doing salinity trend analysis. Where a statistically-significant relation is defined between streamflow and salinity, flow adjusting of water-quality data removes the effects of streamflow on the salinity concentrations and loads. This allows for the evaluation of salinity trends that are not related to dilution or concentration of salinity associated with variation in streamflow.

- Measurement of temporal and spatial progression of surface disturbance is needed. For a detailed summary of available information on surface disturbance and a process for monitoring the temporal and spatial occurrence of surface disturbance associated with energy development see “Surface Disturbance Monitoring Related to Energy Development“ in Appendix 1.
- Measurement or estimation of sediment and salt yields in areas unaffected and affected by energy development will be needed. This information, along with the monitoring of surface disturbance (stressor), will allow for relating whatever trends in salt loading (indicator) measured at the long-term streamflow-gaging and water-quality sampling network for springs, creeks, and rivers (receptors) in the study area.
- Information collected for the temporal and spatial occurrence of surface disturbance, along with long-term flow and water-quality data from springs, streamflow-gaging stations and sampling sites will provide a robust data set for using watershed models to predict the effects that may occur from continued long-term subsurface and surface disturbance on the water resources in the study area. A case study of the application of watershed models in the study area is presented in the “Regional Approach to Modeling Related to Energy Development: Case Study for Water-Quality and Erosion Modeling” in Appendix 1.

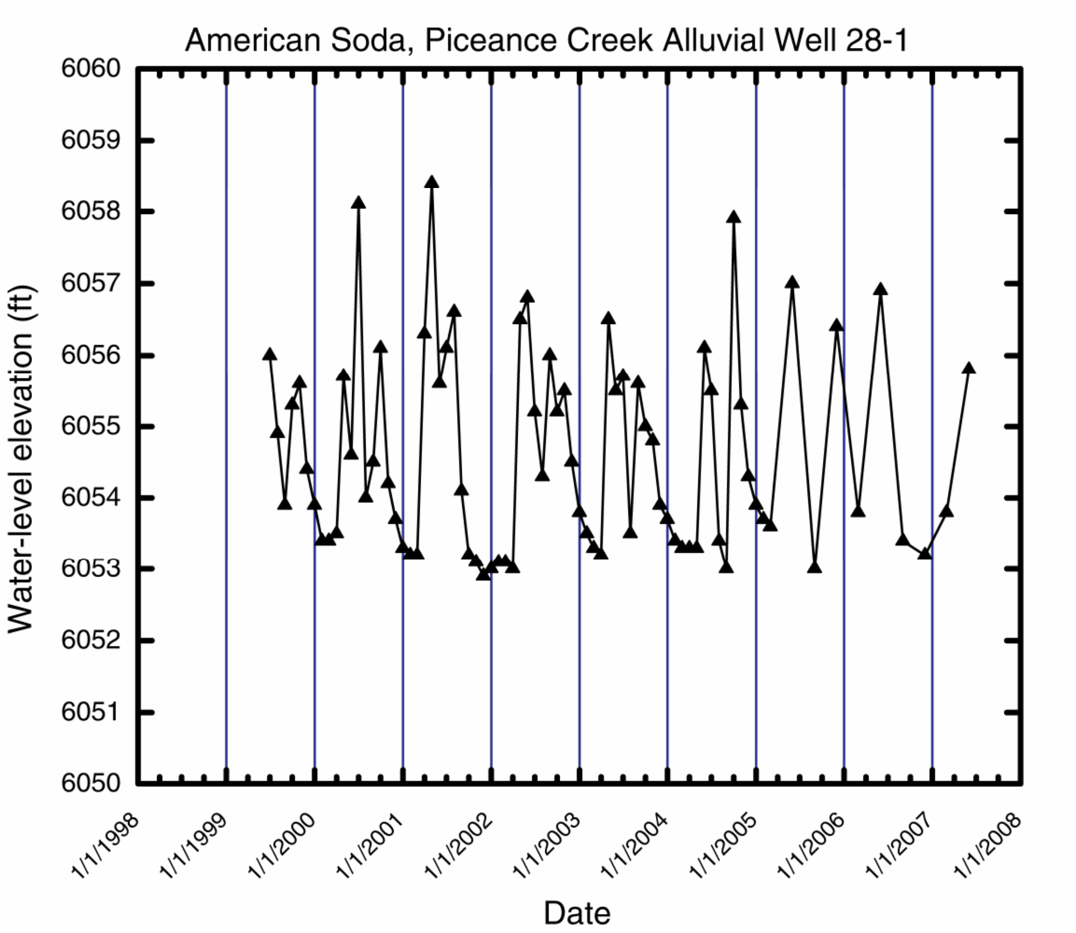


Figure 8. Water-level hydrograph for monitoring well 28-1.

The well is screened from 24 to 34 feet below land surface in the Piceance Creek alluvial aquifer (data courtesy of American Soda, LLP).

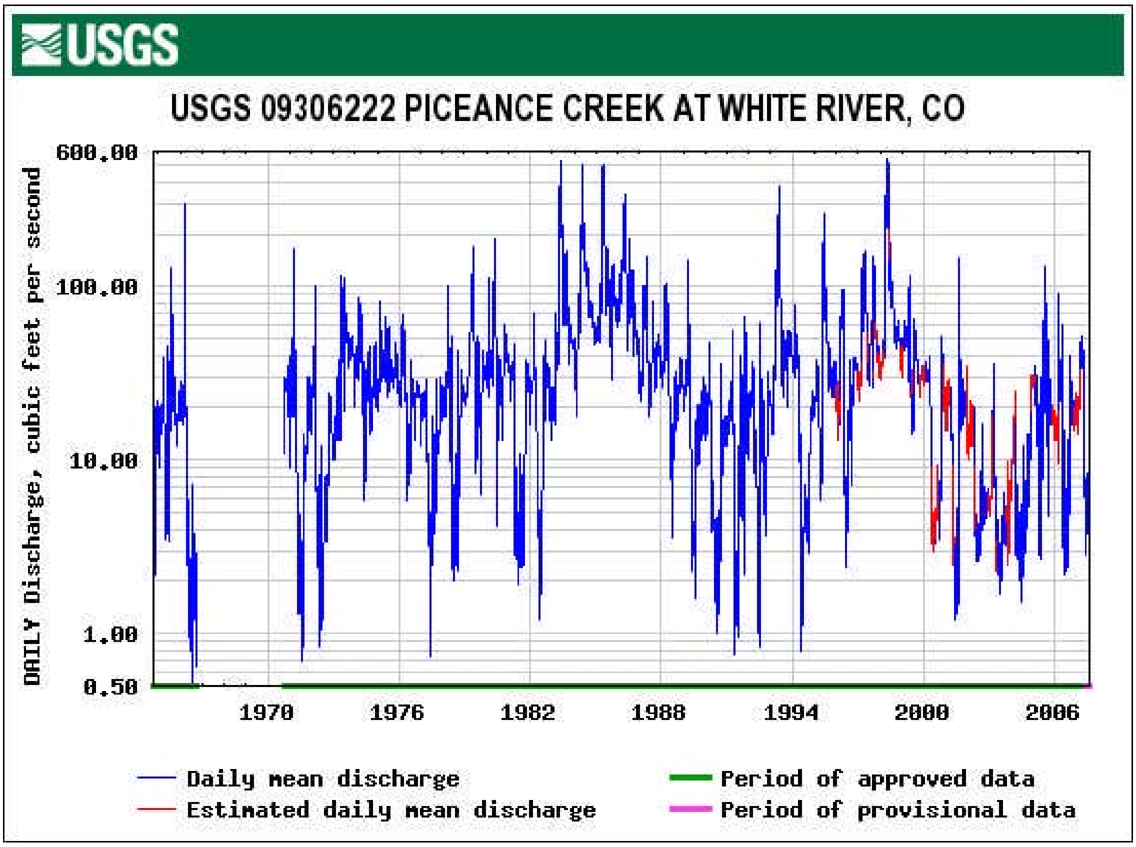


Figure 9. Long-term discharge record for Piceance Creek at White River (data from USGS NWIS website).

Table 4. Summary of selected streamflow and water-quality monitoring sites on the White River, Piceance Creek, and Yellow Creek.

[SW, streamgage; Salinity, periodic samples and/or water-quality monitor; Long-term sites included in analysis by Vaill and Butler (1999), Yellow highlight indicates active data-collection site]

Site Name and USGS ID Number	Drainage Area (mi^2)	Period of Record	Site Description
White River below Meeker 09304800	1,024	SW 1961-07 Salinity 1974-83 1987-07	Quantifies streamflow and water quality on the White River upstream from areas of energy development. Long-term trend site.
Piceance Creek below Rio Blanco (above Stewart Gulch) 09306007	177	SW 1972-88 Salinity 1975-96	Quantifies streamflow and water quality on Piceance Creek upstream from areas of energy development. Long-term trend site.
Stewart Gulch above West Fork 09306022	44	SW 1976-85 Salinity 1975-85	Baseflow is spring fed. Site would monitor ground-water contributions to streamflow. Long-term trend site

Table 4. Summary of selected streamflow and water-quality monitoring sites on the White River, Piceance Creek, and Yellow Creek.- continued

Willow Creek near Rio Blanco 09306058	48.4	SW 1974-85 Salinity 1975-85	Baseflow is spring fed. Site would monitor ground-water contributions to streamflow. Long-term trend site
Piceance Creek above Hunter Creek (above Stewart Gulch) 09306007	309	SW 1974-87 Salinity 1975-87	Long-term step-trend site that along with Piceance Creek Below Ryan Gulch brackets Black Sulphur Creek. Long-term trend site
Black Sulphur Creek near Rio Blanco 09306175	103	SW 1974-83 Salinity 1975-81	Site is located in an area of large-scale development.
Piceance Creek below Ryan Gulch 09306200	506	SW 1964-98 1998-07 Salinity 1971-98 1998-07	Quantifies streamflow and water quality mid basin. Long-term step-trend site
Piceance Creek at White River City 09306222	652	SW 1964-66 1970-07 Salinity 1971-87 1990-07	Long-term trend site located at the mouth of Piceance Creek Watershed. Long-term step-trend site
White River above Crooked Wash near White River City 09306224	1,821	SW 1982-89 Salinity 1982-89	Quantifies streamflow and water quality on the White River mid basin between Piceance Creek and Yellow Creek
Corral Gulch near Rangely 09306242	31.6	SW 1974-07 Salinity 1975-07	Baseflow is spring fed. Site monitors ground water contributions to streamflow. Long-term trend site.
Yellow Creek Near White River City 09306255	262	SW 1972-82, 1988-07 Salinity 1974-82, 1989-07	Long-term trend site located at the mouth of Yellow Creek Watershed. Long-term step-trend site
White River below Boise Creek near Rangely 09306290	2,530	SW 1983-07 Salinity 1983-07	Quantifies streamflow and water quality on the White River downstream from areas of energy development. Long-term trend site.

Step 5 – Estimate the sensitivity of the indicator to detect change, to guide final indicator choice and sampling design

Relatively precise measurements of ground-water levels (±0.01 foot), surface-water discharge (±5 to 10 %), and salinity (± 5%) can be made on a routine basis; however, the precisions are greatly exceeded by natural variability of those parameters in the WRFO in some cases (Figures 8 and 9). Thus, long-term records of water levels and discharge will be needed to distinguish natural variability from ground-water pumping. Long-term discharge data exist for some important surface-water sites, as discussed previously, but not at all sites. No such long-term data are publicly available for ground water in the WRFO. The definition of "long term" is subjective and depends on the intended use of the data. Potential uses of water-level data and the associated time frame for data collection are listed in Table 5 (from Taylor and Alley, 2001). It is important to clearly frame the questions that need to be answered so that data-collection efforts are designed at the proper spatial and temporal scales. For example, for the question of whether ground-water pumping will lower water levels in supply wells on a regional basis (*Step 3*), information in Table 5 indicates that water levels should be collected over a period of years or decades to answer that question.

Table 5 Typical length of water-level-data collection as a function of intended use of the data

Intended use of water-level data	Typical length of data-collection effort or hydrologic record required			
	Days/weeks	Months	Years	Decades
To determine the hydraulic properties of aquifers (aquifer tests)	✔	✓		
Mapping the altitude of the water table or potentiometric surface	✔	✓		
Monitoring short-term changes in ground-water recharge and storage	✔	✔	✓	
Monitoring long-term changes in ground-water recharge and storage			✔	✔
Monitoring the effects of climatic variability			✔	✔
Monitoring regional effects of ground-water development			✔	✔
Statistical analysis of water-level trends			✔	✔
Monitoring changes in ground-water flow directions	✓	✔	✔	✔
Monitoring ground-water and surface-water interaction	✔	✔	✔	✔
Numerical (computer) modeling of ground-water flow or contaminant transport	✓	✔	✔	✔

EXPLANATION

✔ Most applicable for intended use

✓ Sometimes applicable for intended use

Furthermore, answering that question on a regional scale requires measurement sites at multiple locations, not just in the vicinity of development. The frequency of water-level measurements required to define natural variability depends on the location of the well in the regional flow system. The alluvial aquifer is more directly connected to the land surface than the lower bedrock aquifer, so water levels in wells screened in the alluvial aquifer will respond more quickly to precipitation events than water levels in the lower bedrock aquifer. Thus, the frequency of water-level measurements would be greater in the alluvial aquifer than in the lower bedrock aquifer.

To answer the key questions of "Will subsurface disturbance related to gas and oil-shale development increase rates of salt dissolution in groundwater on a regional basis" and "Will subsurface disturbance related to gas and oil-shale development decrease spring discharge and ground-water discharge that supports baseflow to streams on a regional basis?", long-term records of water quality (salinity) and streamflow will be needed to distinguish natural variability from the subsurface and surface impacts on salinity loading to creeks and rivers in the study area. Similar to the length of record needed for monitoring regional effects of ground-water development and the statistical analysis of water-level trends (table 5) data needed to evaluate trends in salinity (indicator) in the White River, Piceance Creek, and Yellow Creek (receptors) will need to be collected for years or decades. Currently (2007), long-term streamflow and salinity data are available for trend analysis to characterize baseline salinity conditions at 6 sites in the study area (Figures 3 and 10 and table 4). Daily streamflow and specific-conductance data (surrogate for salinity) along with the collection of periodic (at most sites bi-monthly) water-quality samples for major ions (e.g. calcium, magnesium, sulfate, alkalinity) are recommended at sites on creeks and streams for characterizing salinity conditions at a sampling site (Lieberman and others, 1987). Collecting similar data for characterization of selected springs representative of regional ground-water flow systems is recommended.

Step 6 – Describe a process by which management can identify thresholds of change requiring a management response

Thresholds of change most commonly addressed by land-use managers are those based on the regulatory process. Administered water rights, for example, may be the appropriate regulatory framework for identifying thresholds of change with respect to stream discharge in the WRFO. Ground-water pumping that reduces stream discharge such that water rights are impaired would trigger a management response. There is no regulatory framework in Colorado for evaluating water-level declines. Thus, thresholds of change could be identified by trends in the data that could lead to unacceptable impacts. Examples of unacceptable impacts related to water-level declines would include the following:

- Industrial, irrigation, or domestic wells go dry or are subject to increased pumping costs.
- Springs go dry or they have reduced ability to support critical habitat.

Both of those examples would require a management response.

Related to the example presented on the increase in salinity loading to area creeks and rivers, salinity loading is not regulated by the State of Colorado. However, BLM is a participant in the seven basin state Colorado River Salinity Control Program as authorized by the Salinity Control Act (1974). An increase in salinity loading that resulted from the effects of energy development on Federal lands or lands where Federal minerals were leased would require a land-management response. Depending on the source of increase in salinity loading, subsurface disturbance or surface disturbance or both, would require the multiple adaptive-management responses to remediate the stressors effect on receptors. An example of an unregulated concern that is not related to water levels and salinity is the issue of stream stability and stream-channel morphology. Changes in stream stability can result from increased unit runoff resulting from surface disturbance in a watershed or the discharge of produced waters to ephemeral streams. Stream-channel stability also can be affected by changes in sediment supply resulting from increased erosion. Increased sedimentation rates in receptor streams can adversely affect aquatic habitat as well. While stream stability is not regulated, a way to evaluate stream stability would be to classify stream-channel conditions in a particular area of concern (Rosgen, 1993) and to monitor changes to stream classification over time. Hydraulic-geometry relations between channel morphology, basin characteristics, and streamflow were established for 18 stream reaches in the Piceance Basin in the 1980s (Elliott and Cartier, 1986), providing reference standards against which future channel morphology changes can be assessed. Changes in channel morphology could be early indicators of channel instability. Another example of an unregulated concern that is not related to water levels and salinity is the issue of aquatic habitat and biology. Biological monitoring is part of the water-quality regulatory structure of the EPA and states. In Appendix I biological monitoring is presented as a reference-based approach to determine the effects of energy development on aquatic biology and habitat. Streamflow, water-level, and water-quality data should be assessed on an ongoing basis to ensure their reliability and to determine whether threshold values and conditions have been reached. By not analyzing data on a regular basis, the hydrologist and land manager run the risk of not recognizing data-collection problems or exceedances of threshold values and conditions. Management should be informed of monitoring results at least once each year through oral presentations, and more frequently if a management response is required. Written assessments of the data should be completed once per year for the permanent record. An example of a written assessment was developed by Spahr (2002 http://pubs.usgs.gov/ds/ds101/) that includes analysis and summary tools for evaluating data collected at a network of water-quality sites in the upper Gunnison River Watershed. The data for each site is summarized and compared to historic data and regulatory thresholds. Trend analysis is done on selected data. These results are compiled into one summary table to provide a concise current overview of water-quality conditions for streams in the upper Gunnison River Watershed.

Step 7 – Identify clear connections between the overall monitoring program and the management decision process

If declining water levels reduce stream discharge below threshold levels (e.g. impair water rights), cause wells or springs to go dry, or reduce the functionality of wells and springs in other tangible ways (e.g. increased pumping costs, loss of aquatic habitat), BLM and the appropriate state regulatory agency will investigate. If water-level declines are the result of anthropogenic activity, then existing monitoring data will be used to identify the specific cause. If existing data are insufficient, then additional data collection may be required to identify the specific cause. In either situation an enforcement action may be necessary to reduce ground-water pumping by an amount necessary for the recovery of discharge to threshold levels and for the recovery of the affected wells and springs to baseline conditions, as defined by long-term monitoring data, or acceptable production capacity of wells that satisfies established water rights. This mitigation effort may be a dynamic process because of natural variability in discharge and water levels. In other words, producers may be allowed to pump more ground water during wet periods than during dry periods. If specific anthropogenic activities cannot be identified, mitigation measures may be applied to all energy operators in the affected area. If water-level declines continue to be a problem, or are anticipated to be a problem as energy development continues in the future, consideration should be given to developing a decision-support system for managing water use in the WRFO (Colorado Division of Water Resources, 2007).

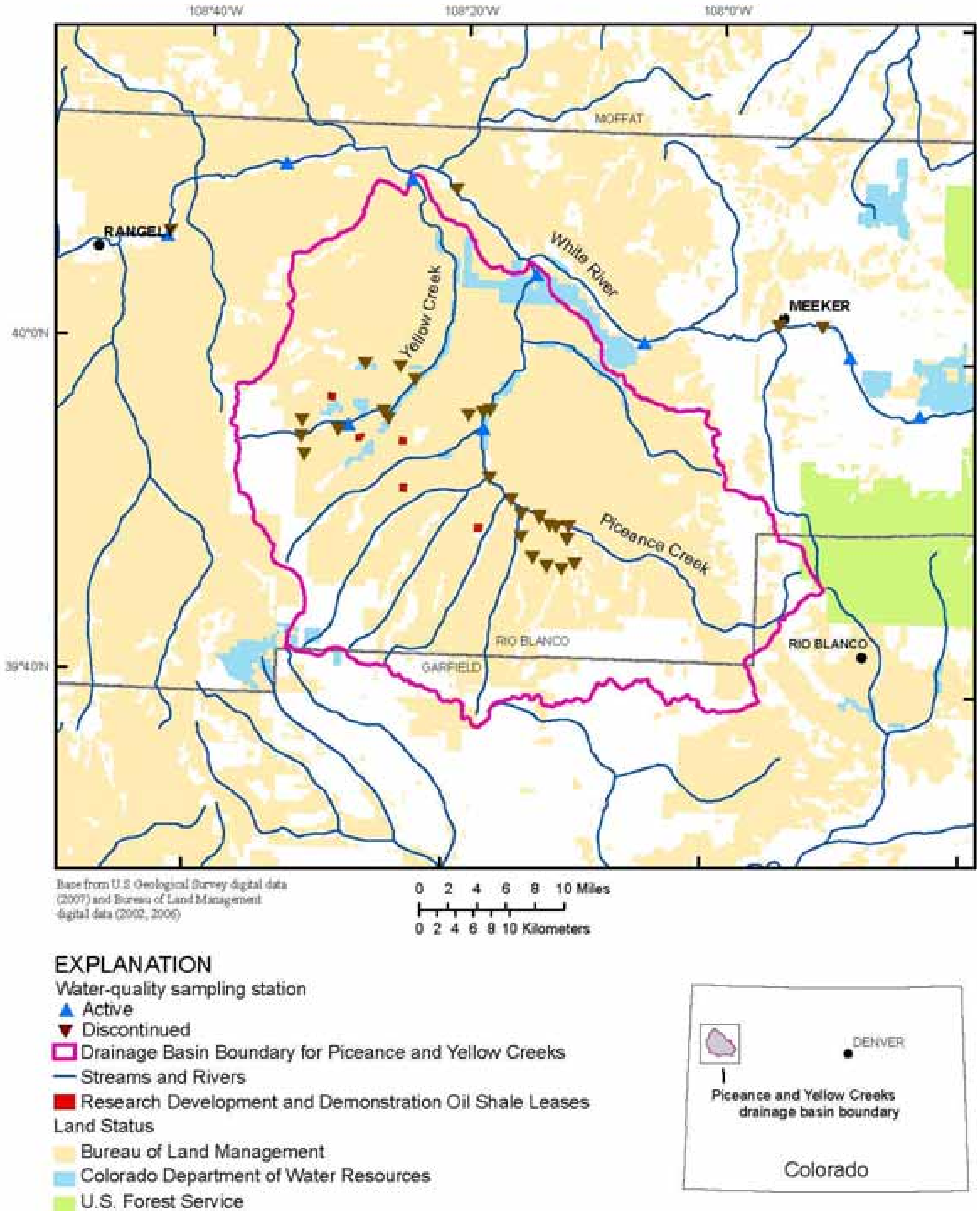


Figure 10. Location of active and inactive water-quality sampling stations.

If salinity loading is found to be increasing in ground water or streams, data from the streamflow and water-quality monitoring network would be evaluated to determine if a particular area of disturbance or natural variability in streamflow and precipitation may be the cause. If the results of that analysis indicate that increased salinity loading is a result of anthropogenic activities then management practices would be evaluated and adjusted to mitigate the effects of the disturbance causing the increase. Changes in management practices may include improved road maintenance, increased stipulations for the rate of development, surface and subsurface, of an area, or the cessation of development activity where management practices are not effective in mitigating conditions that cause increased salinity loading.

The success of Step 7 depends upon regular interaction among the monitoring process, the regulatory process, the land-management process, and the energy industry. The BLM land-managers and industry need to be kept apprised of monitoring results (indicators) so that opportunities to implement remediation in the form of best-management practices can minimize the effects (stressors) from energy development on receptors. Likewise, the monitoring process needs to be responsive to the concerns of management and industry with respect to timeliness of reports, cost of monitoring, and proper focus of monitoring. This communication process can be achieved most efficiently and effectively through oral presentations at the WRFO field office in Meeker and, when necessary, with field trips to areas of concern. Usually, understanding the scope of an issue is helped by visits to the field. It is important to re-emphasize that the process of managing the Regional-Monitoring Framework is likely to be iterative. The Framework will need to be updated as information is developed (collected and interpreted), see objective 3 in step 7 of chapter 1, also see figure 1.

Finally, commitment by management to develop and support an institutional culture that is held accountable for targeted and long-term monitoring along with regular data interpretation to inform the land-management process is vital to the success of any Regional Framework.

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APPENDIX I

Table of Contents

Introduction

The information contained in Appendix I represents approaches for the detailed development of data collection and analysis to meet the long-term needs of application of the Regional Monitoring Framework to support adaptive land management. The following sections "Water Resources Monitoring Frameworks and Assessments, Stream Biology Resource Monitoring Related to Energy Development, Surface Disturbance Monitoring Related to Energy Development, and the Regional Approach to Modeling Related to Energy Development: Case Study for Water-Quality and Erosion Modeling" outline in more detail how various aspects of the Regional Monitoring Framework may be used or implemented. The section on Water Resources Monitoring Frameworks and Assessments provides specific information on the design and implementation of a water-resources monitoring plan. The next two sections outline specific approaches to monitoring the effects of energy development on stream biology and surface disturbance. Each if these two sections outlines a three-phased approach to implement monitoring and identifies specific tasks to be completed. Recognizing that there are limits to how monitoring can inform a process the final section presents implementation of watershed models for the purposes of simulating the effects of energy development on an areas hydrology. That section also includes a case study as an example for completing a Phase I effort.

Water Resources Monitoring Frameworks and Assessments

Monitoring programs for water resources generally have two objectives, one of which is to assess the status and trends in the quantity and quality of water and the second of which is to link status and trends to natural and human factors that affect quantity and quality (Gilliom and others, 1995). Energy development is one of the more visible human activities with the potential to affect water resources on a regional scale in the western U.S. Energy development consists of exploration activities and subsequent production and transport of the resource. Basins like the Powder River in Wyoming have already experienced widespread energy development, but others like the Piceance Basin in Colorado have not. Superimposed on regional energy development is natural variability in water resources resulting from regional gradients in topography, geology, climate, and vegetation which can complicate the understanding of how energy development affects water resources.

One of the most important issues facing the Bureau of Land Management is how to understand and possibly forecast the effects over time of energy development on regional hydrologic systems in the western U.S. so that widespread degradation of the resource can be minimized or avoided. Regional forecasts of those effects based on local-scale monitoring networks would be difficult, if not impossible, without an understanding of the regional context in which those networks exist. Thus, a regional framework for monitoring water resources in the western U.S. is needed that (1) provides context for distinguishing between natural, and (2) human controls on water quantity and quality and that facilitates spatial and temporal up-scaling of local monitoring results.

Monitoring for scientific understanding in support of land management requires a design where sites are selected to represent certain human activities, environmental settings, and hydrologic conditions during different seasons, and to represent interannual variations in hydrology. Monitoring sites may be selected to assess the effects of land-use practices and resulting contamination in streams and aquifers. A monitoring design requires ancillary information on land use, chemical sources of contamination, natural landscape features, and hydrology. Such a design also requires the collection of various monitoring data. For example, over different seasons, water-resources assessments generally show low concentrations of contaminants, such as pesticides, in streams for most of the year—lower than most standards and guidelines established to protect aquatic life and human health. However, the assessments also show pulses of elevated concentrations— commonly 100 to 1000 times higher than during base streamflow—during times of the year associated with rainfall and chemical applications than during other times of the year (Gilliom and others, 2006). Such pulses could result in Clean Water Act violations, affect aquatic life at critical points in the life cycle of aquatic organisms, and also water supplies for short periods. These conditions cannot be described in a meaningful way unless repetitive, time- and streamflow-dependent, monitoring is conducted at given sampling locations, with a substantial part of that sampling focused at times that are prone to large water-quality changes. Multiple samples are less critical in ground water as changes occur more slowly and generally are less influenced by seasonal conditions or individual hydrologic events (Hirsch and Hamilton, 2006).

Monitoring programs need to characterize hydrologic gradients resulting from different geologic or climatic settings. The geologic setting—whether alluvial deposits, sandstone, or igneous rock—affects how readily water and associated contaminants move over the land, into the ground, and between aquifers. For example, geologic formations are an important part of the hydrologic system of the Piceance Basin because all or part of them are aquifers. The aquifers transmit and store water and form a major part of the overall flow system. Aquifers associated with the oil shale in the basin have several permeable zones resulting from fractures and interconnected pores. Geologic beds that are less permeable than the aquifer zones tend to retard ground-water movement but not completely. Similarly, climate can have profound effects on water quantity and water quality. Streamflow and the rate of recharge to aquifers varies seasonally and geographically in the Piceance Basin where precipitation generally increases with elevation and ranges from about 12 to 20 inches per year (Taylor, 1987).

Water quality and biological systems are closely interconnected. Aquatic organisms, such as algae, macroinvertebrates, and fish, are susceptible to water-quality degradation. In Piceance Creek, Covay (in Taylor, 1987) defined a downstream gradient in species composition of benthic–invertebrates related to increased dissolved solids and stream substrate. Water-quality assessments depend on biological monitoring and determinations of how biological response varies among diverse hydrologic settings and conditions related to land use.

Targeted monitoring and the resulting scientific understanding help to answer questions, such as ‘‘Why do water-quality conditions occur and when? Do certain natural features, land uses, human activities, and management actions affect the occurrence and movement of certain contaminants? Is water quality getting better or worse?’’ The information helps decision-makers to more cost-effectively: (1) identify and prioritize those streams, aquifers, and watersheds most vulnerable to contamination and in need of protection; (2) target management actions to specific sources and causes of pollution; and (3) evaluate the effectiveness of those actions over time (Hirsch and Hamilton, 2006). Targeted monitoring may be associated with compliance monitoring, synoptic characterization of streamflow and water-quality conditions (Tobin, 1993; Ortiz, 2000), and the monitoring of impacts to a watershed over time (trend monitoring) (Vaill and Butler, 1999). Another approach is probabilistic monitoring, in which sites are selected randomly across a certain region. This is a useful method for obtaining an unbiased, broad geographic snapshot of ‘‘whether there is a problem’’ and ‘‘how big the problem is.’’ Targeted and probabilistic monitoring designs are both important for answering different types of questions and for providing different types of information that are critical for understanding the ambient resource. Effective decision making requires recognition of, and commitment to, several fundamental hydrologic tenets that underpin all monitoring (Hirsch and Hamilton, 2006). The following discusses these tenets as presented by Hirsch and Hamilton (2006).

Hydrologic Cycle

Water-quality data must be evaluated in a ‘‘total resource’’ context, including all components of the hydrologic cycle. Surface water, ground water, and the atmosphere are all connected, and the interactions among them are crucial to determining streamflow; ground-water recharge, storage, and discharge; the fate and transport of contaminants; and chemical and biological quality. Ground water can be a major contributor to rivers, streams, and other surface-water bodies; contaminated aquifers that discharge to waterways can, therefore, become nonpoint-pollution sources. Quantifying ground-water contribution to surface water is essential for meeting Clean Water Act goals. Exclusion of groundwater monitoring may prevent a full accounting of all available sources and may limit the effectiveness that BMPs could have in future stream protection and restoration efforts. Similarly, surface water can be a major contributor to ground water and, therefore, a major nonpoint-contamination source for aquifers, particularly where high-capacity, public-supply wells are located near rivers and streams.

Hydrology Controls Water Quality

Only part of the water-quality story can be told from monitoring for concentrations of chemical constituents in water without the quantitative hydrologic context and calculation of fluxes. A large part of the variation in water quality at a given location is determined by streamflow. Amounts of contaminants measured at a sampling site can increase substantially from year to year simply because of high stream flows during wet environmental conditions. Water-quality data must be evaluated in concert with water quantity. Concentrations and types of contaminants and their potential effects on ecosystems and drinking-water supplies vary over time and depend largely on the amount of water flowing in streams and the amounts and directions of ground-water flow. Contaminant concentrations vary greatly between low and high flows, during different seasons of a year, and during different hydrologic regimes—such as periods when rainfall, snowmelt, or ground-water inflow dominates river flow. It is critical to monitor water quality under these different hydrologic conditions, and to evaluate the load of material that is transported in a stream and river and delivered to receiving bodies, such as lakes, reservoirs, estuaries, and bays.

Hydrology Controls Timing Of Water Issues

Changes in water quality in surface-water systems can be relatively quick—within days, weeks, or months. Or, changes can be relatively slow, such as in aquifers where changes can take decades because of slow ground-water movement. Without comparable data collected over time, long-term trends cannot be distinguished from short-term fluctuations, and natural fluctuations cannot be distinguished from the effects of human activities. Consistent and systematic long-term monitoring also is critical to evaluating whether environmental and management strategies are working, and for choosing the most cost-effective resource-management strategies (Hirsch and Hamilton, 2006).

To evaluate the effects of energy development on water resources over time, long-term monitoring is needed to provide hydrologic characterization within a historical hydrologic context. This is particularly true for changes in ground-water and sediment quality, which may not be evident for years or even decades.

A long-term, hydrologic context is important when evaluating effects of energy development and management practices. For example, in regional aquifer systems where saturated thicknesses can be large and ground-water residence times can be long, changes in ground-water quality in response to contamination may occur slowly over decades or even centuries (Fogg and LaBolle, 2006). Those gradual trends in water quality are not easily recognized in the absence of long-term monitoring. Just as contaminant concentrations may gradually increase over long time periods, so too may long time periods be required to attenuate or flush contaminants from regional aquifer systems once they become contaminated. Thus, long-term monitoring at critical locations in the flow system is necessary for providing early warning of widespread regional contamination to minimize protracted remediation scenarios.

Shallow aquifers with shorter ground-water residences times, such as alluvial systems, respond much more quickly to contamination than regional aquifers; however, even in those shallow systems years or decades may be required to attenuate or flush contaminants (McMahon and Bohlke, 1996).

The long-term, hydrologic context is also important to sort out the effects of natural variability from the effects of man’s activities. Natural events such as floods or drought often can mask shorter term, human actions with the occurrence of particularly wet or dry years. Only after understanding the patterns within the historic hydrologic record are we likely to recognize any underlying changes that are taking place due to man’s activities.

Predicting Hydrologic Response To Energy Development

The development and verification of predictive tools and models is an essential step in understanding and successfully managing the impacts of energy development on water resources. Such tools are needed to extrapolate or forecast conditions to unmonitored, yet comparable areas, both in space and in time. During a time of increasingly diminishing resources, it is unrealistic to expect to monitor our water resources directly in all places and at all times. Moving from monitoring to modeling ultimately provides for regional assessments of water resources.

The use of predictive tools helps to prioritize contaminant sources and to understand the importance of factors affecting water resources, including surface disturbance, ground-water reinjection, landscape features, and hydrologic transport. Predictive tools can help estimate conditions that often cannot be directly measured, such as the effects of specific management practices or the percentage of contamination in a stream that originates from different sources. For example, the Gulf of Mexico experiences low concentrations of dissolved oxygen each spring and summer largely as a result of large amounts of nitrogen delivered by the Mississippi River, which in turn promotes excessive growth of algae and other nuisance plants and potentially can harm the fisheries. The USGS model SPARROW (SPAtially Referenced Regression On Watershed attributes) shows that a considerable amount of the nitrogen delivered to the Gulf of Mexico originates in distant watersheds in the Mississippi River Basin, such as in Ohio and Tennessee (Alexander et al., 2000).

In addition, models can be used to estimate probabilities that concentrations of selected compounds will exceed a specific value, such as a drinking-water standard or an aquatic-life guideline, at a particular location. The SPARROW model has been applied, for example, to predict in-stream concentrations of phosphorus in streams across the U.S. that meet the EPA recommended goal of 0.1 milligrams per liter to control excessive growth of algae and other nuisance plants. Ground-water modeling has been used to predict the presence of atrazine in shallow ground water within agricultural areas across the nation; model results show the highest detection frequencies of atrazine in parts of the Midwest, Great Plains, Pacific Northwest, and Mid-Atlantic regions where atrazine is heavily used in hydrologic settings that favor the transport of pesticides to ground water (Stackelberg et al., 2006). Similarly, a nitrate model used to assess the risk of nitrate contamination in shallow ground water across the U.S. shows that nitrate concentrations are expected to be lowest in shallow ground water underlying areas with low inputs of nitrogen and poorly drained soils, (such as in parts of the southeastern Coastal Plain), and highest in areas with high nitrogen inputs and well-drained soils that overlie unconsolidated sand and gravel aquifers, (such as in the High Plains of northeastern Nebraska and the western U.S). (Nolan et al., 2002). Although results from these models may not be used directly when making policy decisions, they provide critical insights into the locations of more vulnerable water resources, and help to prioritize where and how we commit resources to remediation and future monitoring.

The details associated with the water-resources monitoring framework and assessments are distributed between the three-phased approach described in the Monitoring Plan Overview. It is expected that some aspects of the modeling plan will carry over between each phase of the monitoring plan while some, (e.g., predicting hydrologic responses) will be confined to a particular phase, in this case Phase 3.

Stream Biology Resource Monitoring Related to Energy Development

The BLM is obligated to uphold the protection of the integrity of surface waters under its management as mandated by EPA through the states under the Clean Water Act Amendments to the United States Pollution Control Act of 1972. The most direct and effective measure of the integrity of streams is the status of its living systems, as they have evolved under specific environmental conditions for millennia (Karr and Chu, 1999). These living systems respond in somewhat predictable ways to human disturbances such as large-scale landscape changes related to energy development. Algae, fish and invertebrate assemblages are useful indicators of the integrity and biological status of streams but all assemblages may not be appropriate in every region. The Colorado Department of Public Health and Environment (CDPHE) is currently developing state-wide analytical tools and guidelines for determining biological status of streams based on invertebrates that will be in place by 2010 (http://www.cwqf.org/Workgroups/Content/Aquatic_Life/Documents/Roadmap%20Revision.pdf). These tools will be used in a state-wide stream bioassessment program (Chris Theel, 2006, oral comm., Colorado Department of Public Health and Environment, Monitoring Unit, Denver, Colorado). Drafts of the analytical tools are currently available (http://www.cwqf.org/Workgroups/Content/Aquatic_Life/Documents/Development%20of%20Biological%20Assessment%20Tools.pdf) and can be used as a guideline to develop a regional approach to stream biology resource monitoring as related to energy development by the BLM in Colorado.

Numerous methods that summarize biological response to disturbance have been used in stream bioassessments (see Metcalfe, 1989; Johnson et al. 1993). Many of these methods use various aspects of community structure and composition. Two commonly used indicators include multimetric indices (e.g. Index of Biotic Integrity, IBI) and multivariate predictive type models (e.g. observed to expected ratios, O/E) (Karr and others, 1986; Wright, 1995; Barbour and others, 1999). Both methods rely on comparisons between calculated IBI or O/E values from sites being evaluated and expected values based on observations from a series of comparable reference sites. Regardless of which indicator is used, correctly and narrowly defining reference condition is imperative to a meaningful assessment. Stoddard and others (2006) clearly discuss the concept of setting expectations of reference condition. Often, reference condition is more appropriately defined as the best available condition where biological communities are the closest to natural as possible for a particular region.

As part of developing IBI and O/E predictive models for state assessment tools, the CDPHE is currently defining reference conditions for Xeric, Southern Rocky Mountain and Western High Plains Ecoregions in Colorado. The Xeric and Western High Plains bioregions in Colorado are under-sampled and in need of a better understanding of reference condition (Chris Theel, 2006, oral comm., Colorado Department of Public Health and Environment, Monitoring Unit, Denver, Colorado). Integrating a BLM regional biomonitoring program with CDPHE will enhance both agencies' bioassessment efforts in the Xeric bioregion of Colorado.

Multimetric Indexes

Multimetric indexes such as the IBI are used as indicators of ecosystem wellbeing that incorporate multiple biological community characteristics to measure overall community response to environmental change (Karr et al. 1986; Barbour et al. 1995). This type of indicator was first developed for fish (Karr 1981; Karr 1991) but has since been widely applied to benthic invertebrates, periphyton, and birds (Bahls 1993, Barbour and others, 1999; Bryce and others, 2002). Metrics are chosen that best discriminate between comparable reference and disturbed sites across a region (Barbour and others, 1999). Example metrics for benthic macroinvertebrate communities might include total taxa richness, tolerant taxa abundance, proportion of scraper taxa, and mayfly abundance among others. In general, metric values are calculated and rescaled to values calculated from reference sites. These rescaled metric values are then summed into a single measure that represents overall biological status of a site often defined as condition, health, or integrity. Bioassessment tools further incorporate threshold multimetric index values that assign biological status into categories (e.g. "good," "fair," or "poor"). The multimetric approach has been widely applied to bioassessment programs in the United States and other countries and is currently one of the bioassessment tools being developed by CDPHE that could be used by BLM to assess the influence of energy development on stream ecosystems.

Multivariate Predictive Models

Researchers in the United Kingdom developed the River Invertebrate Prediction and Classification System (RIVPACS) approach, a multivariate predictive model, to assess site condition based on the taxonomic completeness of a sample (i.e. observed, O) as compared to a regional reference condition (i.e. expected, E) measured as the ratio of O/E (Moss and others, 1987; Wright, 2000). Values can range from 1 (reference condition) to zero (completely degraded). In general, the creation of the RIVPACS type model to calculate O/E consists of two steps: (1) classification of reference sites based on their biologicaly similarity and (2) development of a model to predict class membership of new sites being evaluated. Reference site classification results in defining groups of sites that are biologically similar to one another. The biota from each distinct group of sites is then used for defining the regional reference condition (E) for each distinct set of reference sites. Once expected condition is defined for different reference site types, a discriminate function model is constructed of environmental variables that assign new sites being evaluated with their appropriate reference site for comparison. Discriminate function models (DFM) relate group membership to the variability associated with a set of predictor variables. Typical predictor variables used in these DFMs are not influenced by humans and might include measures of latitude, longitude, basin size, climate, and geology. The DFM estimates the probability that a new site (observation) belongs to a particular group of reference sites. These DFM probabilities are used to weight taxa probabilities of detection by weighting the taxa frequencies of occurrence in each group of reference sites. For further detail on building multivariate predictive models to calculate O/E see Hawkins and Carlisle (2001). This approach has been used in Australia (Marchant et al., 2002), Canada (Reynoldson and others, 2001), New Zealand (Joy and Death, 2003), Sweden (Johnson, 2003), and the United States (Hawkins and others, 2000). A RIVPAC type model is currently being developed for Colorado by CDPHE in cooperation with the Western Center for Monitoring and Assessment of Freshwater Ecosystems (Utah State University, Logan, Utah) as one of the bioassessment tools being developed that could be adopted by BLM to assess the influence of energy development on stream ecosystems.

Phase I: Integrate Existing Data and Assessment Tools

The primary objectives of Phase I are to 1) develop a preliminary understanding of the status of biological systems in the area proposed for energy development, 2) identify data gaps, and 3) design efforts to fill data gaps and deficiencies.

The first step in meeting phase I objectives 1 and 2 is to gather and map existing bioassessment data on the biological status of streams within the region proposed for development. Very little benthic macroinvertebrate work is reported in the literature from the area (Covay and others, 1985; Taylor 1982, 1987) (table 6). There are likely other sources that have been produced by local consultants. The utility of the available data is likely limited in the area proposed for energy exploration and development in Colorado. The most comparable benthic data in the region will likely be available from the CDPHE and possibly from the Western Center for Monitoring and Assessment of Freshwater Ecosystems (Utah State University, Logan, Utah). Nonetheless, it will be important to address if existing data are available that can be applied to bioassessment tools to enhance the current understanding of the status of biological integrity of stream systems in the area proposed for energy development. This preliminary exercise will allow BLM to evaluate if land health standards, State Aquatic Life Use Guidelines, and other relevant health/management goals are currently being achieved or even if reasonable assessments can be made at this time. Additionally, this exercise will likely enhance the premature state of CDPHE current bioassessment tools while identifying the data gaps necessary to make stream assessments. Furthermore, biological data should be compiled on federally or state listed fish species in the area or downstream that might be influenced by energy development activities. These species include but are not limited to Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*), mountain sucker (*Catostomus platyrhynchus*), razorback sucker (*Xyrauchen texanus*), bonytail chub (*Gila elegans*), roundtail chub (*Gila robusta*), and Colorado pikeminnow (*Ptychocheilus lucius*). Other native unlisted species that might be influenced by energy development activities include mottled sculpin (*Cottus bairdi*), flannelmouth sucker (*Catostomus latipinnis*), and bluehead sucker (*Catostomus discobolus*).

Once data gaps are understood, it will be necessary to design an appropriate data collection program to eliminate any data deficiencies. This major task should be coordinated with existing bioassessment programs occurring in the region, mainly with those efforts being undertaken by CDPHE and its supporting agencies. This effort will require BLM to clearly define monitoring objectives, as well as definitive management goals and questions. A major part of this effort will likely be directed towards gaining a better understanding of reference condition (Stoddard and others, 2004) in the area proposed for energy exploration. Data collection efforts addressing deficiencies will begin in Phase II.

The primary products in Phase I include the identification of data gaps and a well-designed monitoring program integrated with CDPHE's current bioassessment program (table 6). As part of this process, detailed conceptual models will be developed that describe how stream biology is expected to respond to energy exploration and development. Additionally, a preliminary assessment of the regional status of streams will be evaluated and presented to BLM managers, industry representatives, and other agency scientists to keep parties informed.

Table 6. Phase I tasks and products for stream biology resource monitoring.

TASKS

- Find relevant existing data and add to common data repository.
- Evaluate the status of sites from existing data using data analysis tools being developed by the Colorado Department of Public Health and Environment or by the Western Center for Monitoring and Assessment of Freshwater Ecosystems. It may be necessary to enhance current bioassessment tools if new data are available.
- Evaluate indicators relative to land health standards, State Aquatic Life Guidelines, and other relevant health/management goals.
- Identify data gaps.
- Coordinate with existing monitoring programs to develop new monitoring programs to fill data gaps to better address the above tasks.
- Clearly define objectives for the monitoring program.
- Create preliminary conceptual models based on the literature and existing data to illustrate and explain potential factors controlling the biological status of streams in areas proposed for energy exploration and development.
- Review of results by an integrated team of managers, industry representatives, and scientists to keep parties informed and focused on management objectives.

PRODUCTS

- Map of the regional distribution of stream assessments already made and additional data that could be evaluated using CDPHE bioassessment tools.
- Preliminary conceptual model of how biological systems might respond to energy exploration and development.
- Plans for an integrated monitoring program designed to fill data gaps and address clearly defined objectives.
- Interpretive report evaluating what is known about the current biological status of streams relative to land health standards, State Aquatic Life Guidelines, and other relevant health/management goals.

Phase II: Begin Monitoring and Expand Predictive Capabilities

The primary objectives of Phase II are to 1) fill data gaps identified in Phase I, 2) design and implement research to test conceptual models designed in Phase I, and (3) improve assessment tools by integrating new data (table 7).

Phase II is an important intermediate step between the evaluation of existing data (Phase I) and fully implementing a monitoring program (Phase III) because it refines our understanding of reference conditions prior to fully implementing the regional monitoring program. Testing the conceptual models will further our understanding of the influence of energy exploration and development on stream ecosystems. Once the assessment tools are improved and reference conditions are defined, any site in the region can be evaluated for compliance of BLM Land Health Standards, CDPHE Aquatic Life Use Criteria, and other management goals.

The primary products in Phase II include refined bioassessment tools as well as a better understanding of the status of streams in the area being explored. As part of this process, conceptual models will be refined and updated with supporting data to help better understand how these systems will respond to energy development and exploration. From this effort, the ability to predict how these systems will respond to energy development and exploration will be enhanced.

Table 7. Phase II tasks and products for stream biology resource monitoring.

TASKS

- Fill data gaps by collecting new data based on the data gaps identified in Phase I.
- Design and implement research to test the preliminary conceptual models designed in Phase I.
- Refine conceptual models and assessment tools by integrating the newly collected data.

PRODUCTS

- Updated common data repository.
- Refined conceptual models and assessment tools.
- Refined assessment of Land Health Standards.
- Interpretive report evaluating the biological status of streams as related to energy exploration and development.

Phase III: Fully Implement Monitoring Program, Assessment, and Predictive Capabilities

The biomonitoring program based on clearly stated objectives that addresses discrete management questions and goals is fully implemented in Phase III. The major outcome of this effort will be the identification of water resources that are impaired by energy development so that corrective action can be taken, followed by continued monitoring (table 8).

Development of a specific monitoring program based on clearly stated objectives for the White River Resource Area is beyond the scope of this document. However, the effectiveness of any bioassessment program is anchored in a well developed understanding of regional reference condition, which will require the collection of additional data. A strategically designed monitoring network will allow BLM to access any site in the sampling frame, determine changes in biological condition over time, and predict future changes in currently undeveloped areas.

Table 8. List of Phase III tasks and products for stream biology resource monitoring.

TASKS

- Fully implement revised monitoring program and continue trend monitoring.
- Determine effects of energy development on stream systems at any scale within the sampling frame.
- Evaluate indicators relative to land health standards, ambient ground-water quality standards, and other relevant health/management goals.
- Identify corrective action where needed.
- Integrated team of managers, industry representatives, and scientists develop and implement corrective actions where necessary (Best Management Practices, BMPs).
- Performance monitoring of BMPs.

PRODUCTS

- Tools for evaluating monitoring results in regional context.
- Monitoring program that integrates ground-water assessment (observation) and ground-water science (understanding).
- Interpretive reports evaluating indicators relative to land health standards, ambient ground-water quality standards, and other relevant health/management goals.
- Interpretive report evaluating the current biological status of streams relative to land health standards, State Aquatic Life Guidelines, and other relevant health/management goals

Surface Disturbance Monitoring Related to Energy Development

The most conspicuous environmental impact of oil and gas development is land disturbance (Figure 11). Surface disturbance from energy development includes both the physical equipment introduced into the landscape as well as the ground from which vegetation has been removed. Because oil and gas exploration, development, and reclamation occur continuously in the Piceance structural basin, the patterns of surface disturbance are constantly changing in this region.

The BLM presently evaluates energy development impacts (including surface disturbance) under the Federal Land Policy and Management Act (FLPMA) of 1976. Its organizational mandate is to manage multiple-use public lands so that the Nation’s need for oil and gas resources is balanced with other resource values to best meet the present and future needs of the American people. BLM assesses energy impacts at both regional and local scales. BLM regional-scale assessments occur during preparation of National Environmental Policy Act (NEPA)-related documents, Resource Management Plans (RMP’s), and Reasonable Foreseeable Development (RFD) technical reports. RFD’s, for example, include acreage estimates prepared by petroleum engineers and geologists for development of large resource areas (such as the Roan Plateau). More localized BLM assessments occur during processing of applications for permit to drill (APD’s). To evaluate APD’s, GIS or GIS -based decision tools, such as CARAT (Computer-Aided Resource Assessment Tool),[1] are used to compare the lease location against development stipulations and other land-use needs.

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[1] CARAT is presently used by the White River and Pinedale field offices. The BLM expects that APD’s will be evaluated in the future using the ePlanning version 2 GIS toolkit to be developed by DOE’s National Energy Technology Laboratory and to be deployed, at least in proof-of-concept form, in 2007.

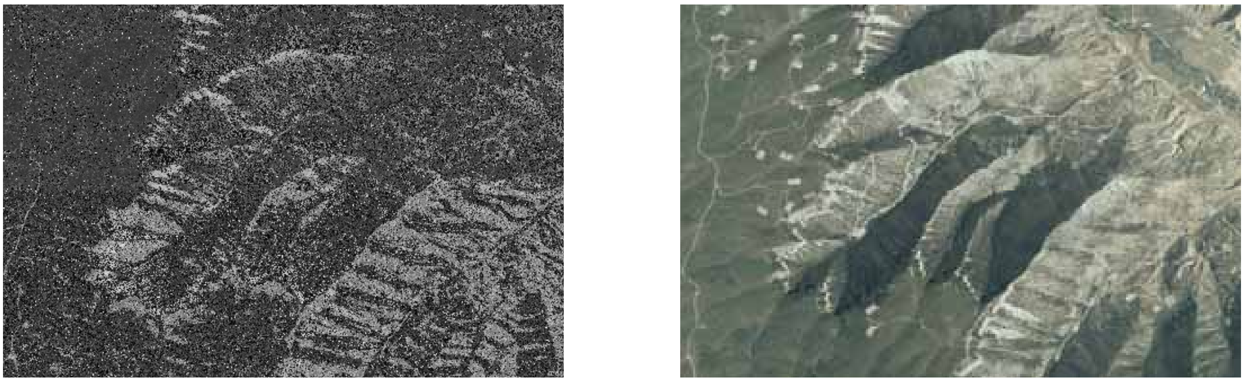

Figure 11. Area west of Parachute Creek and southwest of the Roan Plateau showing past surface disturbance (left photo, 1993) and more recent (right photo, 2005).

Although the BLM presently assesses impacts from oil and gas development, surface disturbance in the Piceance structural basin is particularly intense, both spatially and temporally, and its potential impacts on water and wildlife are poorly understood. Potential impacts are certainly reduced by the energy industry's use of BMP's, such as using smaller well pads and access roads, directional drilling, centralizing production facilities, burying pipelines and utility lines, and generally practicing good land reclamation and land stewardship. Still, the combined and long-term effects of such concentrated disturbance are poorly known for this region because of the present lack of an overarching monitoring plan and ongoing data collection, synthesis, and analysis. Such concentrated, rapid development has the potential to impact water resources:

- High well and road densities cause locally focused patterns of vegetation loss that could alter groundwater infiltration rates and long-term rates of soil erosion. Little is known about how such exposed areas cumulatively affect long-term water quality (Spahr and others, 2000; Albrecht, 2007) or the biological integrity (Stoddard and others, 2004) of intermittent or perennial streams in this region. Aquatic habitat is particularly fragile in such semi-arid streams, and it may, over time, be especially vulnerable to increased sediment loads during storm events.
- The scale of development increases the potential for improper disposal of drilling fluids, cuttings, and water, and also raises the potential for surface water or groundwater contamination. Water quality and riparian habitat data for this region, once again, are sparsely collected and not consolidated. Therefore, judgments regarding the ramifications of surface disturbance on water quality and stream habitat are somewhat speculative and based on investigations in other areas.

Surface disturbance from oil and gas development in the Piceance structural basin also has potential effects on wildlife habitat, including:

- Overall increased cumulative noise, air, water, and light pollution effects at well sites and on roads, with unknown persistent consequences on bird and mammalian species.
- Facilitated entry of so-called synanthropic species (species that benefit from human activity), that access and move about the landscape more easily via pipeline and road corridors (Leu, Hauser, and Knick, 2003). Such human-aided species include bird and mammalian predators (such as magpies and foxes) and displacing species, such as non-native plants.
- A decrease in size of patches of habitat and an increase in the distance between habitat areas (Noss and Csuti, 1994). Landscape fragmentation decreases actual and functional habitat, and is widely acknowledged as detrimental to indigenous wildlife and plant species (McGarigal and Marks, 1995; Knight, et al., 2000).

Periodic mapping of surface disturbance from oil and gas development is integral both to present BLM work and to the proposed monitoring. At a very minimum, repeated mapping provides an overview of current (and potentially historical) land disturbance and of the progress of reclamation. Also, BLM integration of land-use needs under FLPMA can only be done using up-to-date and accurate GIS surface disturbance information. From the standpoint of the needs of the monitoring program, needs surface disturbance locations provide a backdrop of spatial information that guides interpretation of habitat and water quality analyses. Surface disturbance parameters - percentages of disturbance, spatial density metrics (road and well density), distance metrics, and habitat fragmentation metrics - are needed to analyze and monitor effects of disturbance on water and wildlife. Such parameters are used for watershed modeling, for studies of changes in erosion rates, for terrestrial habitat studies, and even for investigations of groundwater recharge zones.

Surface disturbance can be inventoried as five GIS data themes. Four are vector GIS data themes related to oil and gas development: access roads, well sites, processing plants and other larger production facilities, and pipeline routes.[2] The vector data themes do not change at the same rate – access roads and well datasets, for example, require more frequent updates because of new drilling and reclamation.[3] A fifth needed data theme is a measure of 'bare ground' (disturbed and natural) versus other land-use or vegetation categories. This raster land-use measurement of surface disturbance is needed at various scales for monitoring program components, especially for landscape fragmentation and erosion studies. BLM field offices presently use most or all of these data themes; however, the monitoring program will need improvements to data collection mechanisms, most of which would also help the present BLM workflow:

- Because of the scale and pace of surface change in this area, vector data themes, especially access roads and well locations, need to be updated frequently. A data capture protocol needs to be developed to ingest, update, and consolidate accurate surface disturbance data more easily and on a regular basis.

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[2] Although they may be buried and eventually revegetated, gathering lines will have temporary surface disturbance, and it is useful to record their locations as a surface disturbance layer and for water quality monitoring.

[3] Although the new Rockies Express gas pipeline, which will be completed in 2009 to connect Meeker, Colorado to Clarington, Ohio, proves that the other, more 'stable' vector data themes are also changing due to the rapid pace of Piceance Basin energy development.

- Vector data themes need to be consolidated from various sources. For example, available roads datasets should be compared for accuracy and combined if possible into a common data structure, one compatible with in-place BLM workflow and GIS decision tools.
- Data gaps should be identified. Such gaps include both spatial 'holes' as well as missing parameters needed for monitoring. As an example, several additional road parameters would be needed for Water Erosion Prediction Project (WEPP) erosion modeling.[4]
- Bare ground and other land-use/vegetation categories need to be periodically remapped for monitoring. Such mapping is needed at the scale of the entire Piceance structural basin and for small study areas (i.e., for WEPP "hillslope" drainages which vary in size from tens to a few hundred square kilometers).

Much of the first phase of the surface disturbance work will entail determining which combination of data capture methods is the most effective and economical. Surface disturbance data can be captured and updated in three basic ways, each involving different skills and personnel requirements:

- *GPS data collection of vector data*. For the Piceance structural basin, GPS locations of roads and all oil/gas facilities are being collected annually by the two counties in which energy development is primarily occurring.[5] As another example, energy companies provide GPS locations of planned and actual wells to the Colorado Oil and Gas Conservation Commission, from which Colorado BLM offices acquire well location data. GPS data collection is an inexpensive means of filling spatial data gaps and of collecting additional data parameters.
- *Manual vector feature delineation by interpretation of aerial photography or high-resolution satellite imagery.* Periodically collected orthophotography is available as part of a national program, USDA's National Agricultural Imagery Program (NAIP). The BLM White River Field Office, for example, recently updated their roads and trails layers using 2005 NAIP imagery. In this region, however, NAIP imagery presently is collected with a 5-year repeat frequency, a cycle that may be too long to monitor the rapid Piceance Basin energy development. Another disadvantage to NAIP imagery is that it is not color-infrared, although special acquisition of such imagery can be negotiated at additional cost. If inexpensive aerial photography is available, manual digitizing of vector features is labor intensive but can be cost effective. Manual feature delineation from imagery, combined with data collected annually by local counties via GPS, may be an economical way to periodically update vector data themes.
- *Automated delineation of raster bare ground and of vector data themes from imagery.* Automated classification of medium-resolution LANDSAT ETM+ 1999 to 2003 imagery,[6] for example, was used to produce NLCD2001, Southwest Regional Gap, and LANDFIRE land-use/vegetation categories (see Appendix). The panchromatic band of high-resolution imagery optionally could be used to enhance the resolution of medium-resolution imagery and map bare ground. To develop finer-grained maps of bare ground and other land use for small study areas,

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[4] Road parameters include: road surface (natural, gravel, paved), traffic level, road gradient, road width, fill slope gradient, fill slope length, buffer gradient, buffer length, soil texture, percent of rock in soil, and road section length (high point to drainage point, low point, culvert, cross bar, etc.).

[5] Rio Blanco and Garfield counties.

[6] On 31 May 2003, the Landsat Enhanced Thematic ETM + instrument began to malfunction, causing the imagery to exhibit wedge-shaped gaps between scan lines which vary in size across a scene. The monitoring program will have to evaluate whether current LANDSAT is still accurate enough for land-use classification or whether other medium-resolution satellite imagery is more suitable.

aerial photography or high-resolution satellite imagery[7] can be collected and analyzed economically. In addition to bare ground, vector features could also be updated using automated methods and NAIP or high-resolution satellite imagery. Satellite imagery, for example, has been used successfully to vectorize roads, pipelines, and well pads in parts of the Powder River Basin (McBeth, pers. comm., 2007). The advantages of automated extraction of vector data include savings in personnel time. The disadvantages are that some cleanup of the extracted features probably would be involved, and if high-resolution satellite imagery is used as the base, the imagery has a relatively high cost for large areas. However, vector data can be extracted from the same base imagery used for manual digitizing, and such features provide a better starting place for manual digitizing.

Phased Management Plan for Surface Disturbance

Surface disturbance dataset development would be integrated in the same three-phase structure described elsewhere in this report for all monitoring components. It should be noted that each phase consists of a stage of work and does not necessarily equate to a single year of time.

Phase I: Integrate Existing Data and Models

Phase I, for the monitoring components in general, is a data collection and evaluation phase. At the beginning of Phase I, current BLM workflow and the monitoring program would be analyzed to inventory the specific surface disturbance metrics and data themes needed, and to decide how often updates are needed. Existing vector surface disturbance GIS datasets would be collected from various sources, including any datasets available from energy companies. These datasets would also be examined for quality, for spatial data ‘holes,’ and for missing parameters/data attributes needed by the monitoring program. These additional data attributes would be collected using GPS, and GPS may be used to fill in spatial gaps as well. During Phase I, vector GIS datasets for each surface disturbance data theme (roads, well pads, other production facilities, and pipelines) will be evaluated to determine what related datasets could be consolidated into a common data structure that would be made compatible with existing GIS decision tools. For updated or refined regional land-use/vegetation categories, medium-scale satellite imagery also would be obtained. For smaller study areas/drainages, high-resolution satellite imagery or aerial photography would be acquired to generate detailed raster bare ground/land use categories and optionally to try to generate vector features. Also, costs would be determined for participating in the existing NAIP aerial photography program, specifically for obtaining a color-infrared product, a shorter repeat frequency, and 1m-resolution imagery for the Piceance structural basin. Tables 9 and 10 below detail the tasks, time requirements, and products expected from this initial phase of work.

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[7] Digital Globe or GeoEye high-resolution commercial saetellite imagery products. Such products vary in spatial resolution from 0.6m (Digital Globe Quickbird) to 1m (GeoEye IKONOS) for panchromatic band and 2.5m (Quickbird) to 4m (IKONOS) MSS bands. A new GeoEye satellite, GeoEye-1, scheduled for summer 2007 launch will provide .41m panchromatic and 1.65m MSS imagery.

Table 9. Tasks associated with Phase I.

Task
• Develop an understanding of the current BLM field office work flow and determine specific surface disturbance metrics required for the present BLM workflow and for the monitoring plan and how often they each should be updated. • Acquire and inventory data quality of surface disturbance datasets: roads, wells, pipelines, and larger production facilities from BLM, state, local, and private sources. Identify the most accurate datasets and data gaps. • Develop a common data structure to merge good quality surface disturbance vector data themes and integrate the data structure into any in-place GIS-decision making tools. • Collect GPS vector data for missing parameters needed by the monitoring program for small study areas. Optionally test the use GPS to collect locations of roads, wells, processing facilities, pipelines to fill in spatial data gaps. • Acquire and prepare medium-resolution, regional satellite imagery for deriving bare ground and other land use categories; also field collection using GPS of disturbed areas. • Acquire and prepare high resolution satellite orthoimagery for small areas to derive bare ground and other fine-grained land-use categories; also field collection using GPS of disturbed areas to use in classification. • Evaluate the cost/benefits of partnering with NAIP program to acquire color infrared imagery, shorter repeat collections (2-3 years) and/or 1-m resolution aerial photography for the Piceance structural basin area.

Table 10. Expected products from Phase I.

PRODUCTS
• List of specific surface disturbance datasets and metrics needed for land assessments and by the monitoring program. • Consolidated data structures for individual vector surface disturbance datasets: roads, wells, pipelines, and oil/gas facilities. • Acquired medium-resolution satellite imagery for the overall Piceance structural basin. • Acquired high-resolution satellite imagery for two watershed monitoring areas. • Cost/benefit analysis of acquiring improved, more frequently collected aerial photography via the existing NAIP program.

Phase II: Begin Monitoring and Expand Predictive Capabilities

During Phase II monitoring will begin. Surface disturbance GIS vector data themes, such as roads, will be combined as much as possible. During this phase, automated methods to develop surface disturbance raster (and possibly also vector) data from imagery will be developed, and the time frames required will depend on the scope of the need and the method used. Data developed from imagery processing will be geared primarily to support the terrestrial habitat, watershed, erosion, and groundwater modeling that will begin during this phase. Also in Phase II, a protocol will be developed to facilitate updates of surface disturbance data. Tables 11 and 12 itemize the expected tasks and deliverables from this phase.

Table 11. Tasks associated with Phase II.

Task
• Combine related datasets into single datasets by theme. The data structures of the combined layers will be made compatible with GIS decision-making tools in use by the BLM offices.
• Develop a methodology for mapping bare ground/land-use categories for small study areas using aerial photos or high-resolution satellite imagery. Optionally develop a method for extracting vector features.
• Develop a method to map medium-resolution land-use categories for entire Piceance structural basin.
• Establish partnership with NAIP program to acquire more frequently collected imagery.
• Develop and begin testing a conceptual protocol/mechanism to recurrently capture and integrate surface disturbance data into the BLM land assessment and monitoring programs.

Table 12. List of Phase II Products.

PRODUCTS
• Combined and complete roads, wells, pipelines, and oil/gas facilities spatial datasets.
• Map of bare ground and other land use categories in overall Piceance Basin and documentation of methodology used.
• Map of bare ground and other land use categories in small study areas for model inputs, and documentation of methodology used.
• Documentation for a mapping protocol for extracting raster bare ground data and optionally for extracting vector features from imagery.
• Preliminary protocol for importing and updating digital surface disturbance data that meets the needs of BLM assessments and of developing monitoring programs.

Phase III: Fully Implement Monitoring Program, Assessment, and Predictive Capabilities

During Phase III, monitoring will be fully implemented to test for impacts to water and wildlife resources. Because this phase relies heavily on the outcomes of Phases I and II, specific tasks, products, and time requirements are not yet known. Phase III is envisioned at this point to continue updates of surface disturbance data (which the BLM may do internally or chose to contract) and also to implement a data update protocol. Tasks and products associated with Phase III are listed in tables 13 and 14.

Table 13. Tasks associated with Phase III.

Task
• Continued, ongoing integration of surface disturbance data from various sources into single data themes.
• Possible ongoing GPS collection of roads and oil/gas facilities information for areas not annually updated by county governments.
• Possible acquisition on a periodic basis (possibly 2-3 yrs) of new aerial photo or satellite imagery: medium and high resolution to update vector features and/or bare-ground categories for monitoring plan.
• Testing and implementation of data updating protocol for surface disturbance data.

Table 14. List of Phase III Products.

PRODUCTS
• A plan and a tested mechanism for periodic collection and updating of surface disturbance data based on the needs of the organization.
• Assistance, if needed, with data acquisition and updates, especially with deriving surface disturbance products from periodically collected imagery.

Regional Approach to Modeling Related to Energy Development: Case Study for Water-Quality and Erosion Modeling

The data accumulated through the implementation of a monitoring program can be used to identify current conditions and trends in relation to past conditions. Data can also be used as a template from which forecasts of probable conditions can be made. Although assessing trends and conditions is important to understanding the health of an area of interest, the BLM is most interested in predicting the cumulative effects of energy development on an area. A means of prediction advocated by the National Research Council (NRC) in its publication “Opportunities to improve the U.S. Geological Survey National Water Quality Assessment Program,” is the use of water quality models to predict, both spatially and temporally, the effects of anthropogenic changes on environmental health (NRC, 2002). The NRC goes on to state that, “Understanding and prediction, embodied in water-quality models, are the cornerstones of water resources management for the future” (p 122).

The benefit of using a water-quality model to better understand an area is that the land managers have a tool with which to assess the current conditions of the area, identify important environmental processes, and examine the effects of proposed changes in management. Historical data are used to develop a model and a conceptual understanding of the environmental processes occurring in the area of interest. During model development, the validity of conceptual understanding can be tested to ensure the correct processes are being simulated. By validating the conceptual understanding, more confidence can be had that results obtained from model simulations are realistic or actually occur. The confidence gained also improves the reliability of the model when it is changed to examine the effects of various potential management scenarios. The results of these simulations would seek to answer questions identified in the monitoring plan and would identify how changes in land use, soil properties or stream networks might influence the area.

Water-quality models can take several forms. The models can vary from simple regression models (simulate specific environmental processes at specific points and times) to theoretically complex, fully distributed models (simultaneously predict numerous processes at any number of places and times). The complexity of the model should be considered early in the modeling process and should reflect the objectives of the monitoring plan. Unless the results of a complex model address the relevant questions, a simpler model is preferred. When modeling systems where water quality is a concern, hillslope models, in-stream or hydraulic models, or watershed models are often used. While these types of models can be developed for the specific area of interest, the process can be laborious and may produce results the integrity of which may be questionable to the scientific community. Fortunately, there are numerous water-quality models available that are often free and produce reliable, respected results. An extensive list of contemporary models has been made available by Singh in his book *Watershed Models* (Singh, 2005).

An additional list of models is available on the Internet from http://www.wiz.uni-kassel.de/model_db/models.html (accessed 5/7/07).

As the modeling is being conducted to answer questions using data collected as part of the monitoring program, it is essential to consider the data requirements of the model or models when developing a monitoring program. Specifically, the temporal and spatial scales at which models will be developed must be identified. By identifying the data requirements of a model prior to implementing a monitoring program, the value of the monitored data can be increased. Admittedly more data is always better than less, but for example, if a model requires daily data it is inefficient to collect data at a smaller time-step. Deciding on the temporal scale to work with is relatively straightforward when considering the questions the monitoring program is designed to address. For in-stream water-quality it is common to use a daily time-scale because of the total maximum daily load requirements established by the US Environmental Protection Agency.

Selecting the spatial scale(s) to model requires considering how indicative the environmental processes occurring in small areas within the area of interest are of processes occurring throughout the area of interest. If a small area is deemed representative of adjacent smaller areas or the larger area, then a model may only need to be developed for the representative small area. Correspondingly, a more intensive monitoring network would be installed in the smaller area than in other parts of the large area. An example pertinent to assessing the effects of energy development on an environment would be to develop a model for a watershed in which energy development will occur and develop another model for a watershed in which no development will occur. Modeling the two systems would facilitate the isolation of anthropogenic impacts on the environment. This approach corresponds to the paired watershed monitoring approach listed by the NRCS in the “National Handbook of Water Quality Monitoring” (NRCS, 1997).

With the above considerations in mind, it is possible to outline a framework by which a model can be selected and applied to an area. The outline has components of those presented by Beven (2001) and Abbott and Refsgaard (1996), it has been tailored to fit the other outlines presented in this document, and it consists of a three-phased approach. The majority of modeling work would be conducted in the first phase. Improvements and alterations to the models would be made in the successive phases as new objectives and scientific questions arise. The phases are as follows:

Phase I. Integrate Existing Data and Models
Phase II. Expand Predictive Capabilities
Phase III. Fully Implement Modeling Program

Tasks within each of the phases of the modeling program are outlined in the following sections. To better illustrate how the tasks could be accomplished, a potential modeling application addressing erosion and sediment transport processes will be described after the explanation of Phase III..

Phase I: Integrate Existing Data and Models

The primary objectives of Phase I for modeling are identical to those developed for the developing a regional ground-water monitoring program and are to (1) develop a preliminary understanding of the regional hydrologic system through the use of models and existing information, (2) identify data gaps in the understanding, (3) design new monitoring programs to fill data gaps, and (4) identify indicators of energy impacts on water resources. In general though, several tasks must be accomplished in Phase I when applying any model.

Phase I Tasks

1) Establish areas and environmental variables to model. Identified by stakeholders when developing the monitoring plan through personal experience and available literature.
2) Find relevant, existing data and add to common data repository. The data would consist of temporal and spatial data available at coarse and fine resolutions and be subjected to a thorough quality-control analysis. Examples of temporal and spatial data are listed below (temporal data is listed as point data as it is often collected at a specific location).
    a. Point data
        i. Stream gages, climate stations, well locations, water quality recorders, atmospheric deposition collectors
    b. Line data
        i. Streams, roads, man-made waterways
    c. Areal data
        i. land-surface elevation, land use, soil, bedrock, surface and subsurface disturbances, chemical applications, land-ownership boundaries, grazing areas
3) Establish spatial and temporal boundary conditions for the area(s) to be modeled. These boundaries could take the form of topographic boundaries, regional groundwater flow boundaries, the period of record to model, and extreme values of the environmental variable to be modeled.
4) Develop general mass balances of physical, chemical, and biological parameters for the area to be modeled based on available literature.
    a. Analyze atmospheric, solid media, and dissolved and suspended particulate data in three-dimensions and through time.
5) Create preliminary conceptual models to illustrate and explain factors controlling the status and trends of physical, biological and chemical variables.
    a. Assess temporal and areal distribution of precipitation. Does evaporation exceed precipitation annually or seasonally? Does precipitation infiltrate or runoff? Does precipitation fall predominantly as snow?
    b. Analyze soils. Are they anisotropic? Do preferential flow paths exist? Do restrictive layers exist? Do perched water-tables develop?
    c. Analyze temporal and spatial distribution of vegetation. Perennial or annuals? What are the rooting depth, density and size? Physical and chemical consumptive requirements?
    d. Analyze streamflows areally (gaining/losing reaches) and temporally to gain understanding as to where potential GW discharges may flow.
6) Identify potential models based on the conceptual models and the spatial and temporal data identified in Tasks 2 and 3, being sure to address:
    a. The need for model complexity (lumped vs. semi-distributed vs. fully-distributed, empirical vs. conceptual vs. physically-based, annual vs. seasonal vs. daily vs. event)
    b. The cost-effectiveness of selecting an available model versus developing a model independently
    c. The number of models required, which depends on the environmental variables for which modeling has been deemed necessary
    d. The ability of the model to be used for forecasting, upscaling or downscaling
    e. Restrictions due to the monitoring data strategy

    It is essential to modeling success that the model selection process not be subjected to internal pressure recommending the use of specific models.

7) Create preliminary numerical models to simulate the fluxes of environmental variables.
    a. Gather necessary ancillary data and process GIS and temporal data as needed.
    b. Identify environmental variables the data that can be used in objective functions during calibration (streamflow, evapotranspiration, for example).
    c. Establish performance criteria considering: the period of record available for temporal data, the location of the area being modeled, the mass balance created in task 4, and the performance criteria used by previous studies.
    d. Conduct a simulation.
    e. Assess model performance and whether the model requires calibration. If so, can the model be calibrated manually or does it require an automated optimization tool.
    f. Conduct a sensitivity analysis of model parameters.
    g. Calibrate the model by adjusting parameters identified in the sensitivity analysis.
    h. Repeat steps **d – g** until either the performance criteria are reached or the model is unable to perform more efficiently.
    i. Validate the model by simulating a different period of record than used during the calibration and assess the model performance identically. A model is validated if it meets the performance criteria.
    j. Quantify the error associated with model.
    k. Compare modeled results to those expected when considering the conceptual model. Are they similar? If not, which model requires adjustment?
8) Examine means of improving the modeling of environmental variables.
    a. Account for model performance and whether another model may perform better. Identify the data necessary to improve current model performance, or apply a different model
    b. Determine whether upscaling or downscaling is required and identify the necessary data
9) Coordinate with existing monitoring programs and develop monitoring programs to fill data gaps.
10) Coordinate with resource managers to identify surface-water quantity and quality indicators of energy impacts. Evaluate indicators relative to land health standards, surface-water quality standards, and other relevant health/management goals.

Several products will be completed following Phase I. Perhaps most importantly the scientists will have a detailed understanding of the environmental processes at work. More tangible products from which to base further research will be the temporal and geospatial data and the calibrated models which will be used to make forecasts as to the impacts of energy development on the environment. A list of products is given below.

<u>Products</u>

1) Common data repository containing existing available data (integrate data from all disciplines).
2) Maps/GIS coverages of several environmental variables that control surface water movement and quality.
3) Preliminary conceptual model of environmental variables.
4) Preliminary numerical model of environmental variables.
5) List of indicators of energy impacts on surface-water resources.
6) Plans for monitoring programs to fill data gaps and for improved and more specialized modeling.
7) Interpretive report evaluating baseline conditions of environmental variable quantity and quality.
8) Interpretive report evaluating indicators relative to land health standards, surface-water quality standards, and other relevant health/management goals.

Phase II. Expand Predictive Capabilities

With the initial models developed, calibrated, and validated it is possible to use the models to predict how the area of interest might respond to anthropogenic changes. The developed models are a means by which the effects of many scenarios of change can be evaluated in a relatively short time. An additional benefit is that the models provide an objective, scientific interpretation of the effects of change.

Designing a forecasting model involves a number of Tasks, as listed below. For forecasting with environmental models it is often necessary to be able to predict climate. Some models have built-in weather generators which use climatological statistics based on previous weather data to predict climatic variability. When weather generators are not available, ensemble predictions are commonly used in environmental modeling for forecasting. To incorporate potential future climate conditions into a forecast, statistically downscaled results of a forecasting global climate model have been used. Similar to the format of Phase I, an example of a forecasting application will be presented following the required Tasks.

Phase II Tasks

1) Identify environmental variables for which forecasting trends are desired and develop trend-monitoring program for such variables.
2) Implement trend-monitoring program for indicators.
3) Periodic review of monitoring results by an integrated team of managers, industry representatives, and scientists to keep parties informed and focused on management objectives.
4) Forecast trends in environmental variables using validated models.
    a. Identify the method used to acquire data for forecasting (e.g. ensemble variable prediction using previous data or output from another model).
    b. Identify scenarios that could potentially influence the environmental variables.
    c. Determine a range of influences within each scenario to include at least a minimal influence, an extreme influence, and a potentially unrealistic influence.
    d. Conduct simulations.
    e. Analyze results and identify the simulated trends in the environmental variable.
5) Coordinate with resource managers to update indicators using model results. Evaluate indicators relative to land health standards, surface water quality standards, and other relevant health/management goals.
6) Revise conceptual and numerical models with data from Tasks 1-3. Revise forecasts of regional effects of energy development on water resources.
7) Revise monitoring program to address new data needs.
8) Revise trend-monitoring program on the basis of Task 5.

<u>Products</u>

1) Updated common data repository.
2) Revised conceptual and numerical models.
3) Revised list of indicators of energy impacts on surface water resources.
4) Revised monitoring plans.
5) Interpretive report evaluating indicators relative to land health standards, surface water quality standards, and other relevant health/management goals.

Phase III: Fully Implement Monitoring Program, Assessment, and Predictive Capabilities

Model results from Phase II will be evaluated in a regional context within Phase III. The areas that were modeled were deemed representative of the larger area of interest in Phase I. Given the results of the previous modeling work, conclusions can be made that are relevant to the entire system. Additionally, during this phase of modeling the models will be adjusted to further explore the influence of anthropogenic changes on either parameters studied earlier, or to examine new parameters.

Phase III Tasks

1) Implement revised nested monitoring program to fill data gaps and allow for upscaling and downscaling of results.
2) Implement revised trend-monitoring program for indicators.
3) Forecast regional effects of energy development on water resources.
4) Regular review of modeling results by an integrated team of managers, industry representatives, and scientists to keep parties informed and focused on management objectives.
5) Evaluate indicators relative to land health standards, surface-water quality standards, and other relevant health/management goals.
6) Identify corrective action needs.
7) Integrated team of managers, industry representatives, and scientists develop and implement corrective actions (Best Management Practices, BMPs).
8) Performance monitoring of BMPs.

Products

1) Updated common data repository.
2) Conceptual and numerical models that explain monitoring results in framework of controlling natural and anthropogenic factors.
3) Flexible and scalable monitoring program that assesses regional effects of energy development on water resources.
4) Best Management Practices.
5) Interpretive reports evaluating indicators relative to land health standards, surface water quality standards, and other relevant health/management goals.
6) Interpretive reports explaining monitoring results in framework of controlling natural and anthropogenic factors.

Conclusions

Achieving a fully implemented modeling program, as described in Phases I-III provide detailed information regarding the effects of energy development on sediment production. However, financial constraints often limit how much work can be accomplished. With this in mind it is potentially beneficial to outline less demanding alternatives of modeling that will still provide valuable information. The modeling example to follow is potentially the most detailed and informative. The coarsest alternative would be modeling only the White River, Piceance Creek or Yellow Creek watersheds to their outlets. An alternative of intermediate detail would be to monitor sediment at multiple points within one of the watersheds and then develop models able to account for sediment produced from the areas contributing to monitoring points. Regardless of which approach is selected it is imperative to understand that the success of both the monitoring program and the modeling are inter-dependent.

Example of Phase I : Integrate Existing Data and Models

Task 1: Using the tasks in Phase I-III it is possible to incorporate a modeling program into a monitoring project. The following example uses the Phase I tasks to illustrate the development of nested sediment transport models for areas within the Piceance Basin, specifically within the area of Colorado draining the White River. Within the White River Basin, sediment transport will be examined for the White River drainage, the Piceance Creek subbasin, and hillslopes within the Piceance Creek subbasin. The specific objective of the modeling is to estimate the seasonal and annual sediment yield produced at the outlet of each area. Incorporated into this effort will be the identification of how introducing roads and well pads will impact sediment production.

Task 2: Some readily available spatial and temporal data exists in the form of publicly available data produced by different agencies of the Federal Government.

a. Climate data is available from the National Weather Service at: http://www.ncdc.noaa.gov/oa/ncdc.html
b. Streamflow data, for Colorado, is available from the U.S. Geological Survey at: http://waterdata.usgs.gov/co/nwis/sw
c. Digital elevation data is available from the U.S. Geological Survey at: http://seamless.usgs.gov
d. Soil data is available from the Natural Resource Conservation Service at: http://soildatamart.nrcs.usda.gov
e. Landuse data is available from the U.S. Geological Survey at: http://www.mrlc.gov/mrlc2k_nlcd.asp
f. Maps of streams are available from the U.S. Geological Survey at: http://nhdgeo.usgs.gov/viewer.htm
g. Sediment data is available from the U.S Geological Survey at: http://co.water.usgs.gov/sediment

In addition, data similar or identical to that listed above are available for the area from the state of Colorado at: http://cdss.state.co/DNN/Home/tabid/36/Default.aspx

Some of the data within the data repository will have accompanying maps/GIS coverages. Specifically, the digital elevation data, soil data, land use data, and stream maps will all be available in a format readily accepted by a GIS. It is essential, however, that each layer of spatial data is in the same projection. A common projection is the UTM projection although the Albers projection is often used due its ability to retain spatial accuracy. Temporal data, such as streamflow, climate and sediment information, are often georeferenced to a specific point where the environmental variables are measured. These point data will most likely need to be created within the GIS. Coordinates for the measurement points often accompany the temporal data.

Task 3: The spatial and temporal boundary conditions of the model(s) are dependent on the environmental variable of interest; in this example, the environmental variable is the sediment yield resulting from erosive processes. As the erosion of hillslope sediment is predominantly induced by precipitation, it is reasonable to use topographic divides as the spatial boundary. Figure 12 depicts topographic boundaries for the White River and Piceance Creek watersheds. Within the Piceance watershed 3 hillslopes would be identified; one hillslope where roads and well pads are to be introduced, a second with roads, and another relatively undisturbed hillslope. A hillslope is defined as an area of a watershed from the topographic divide to the stream. Ideally, the hillslopes are adjacent to one another and are similar, at least conceptually, in their hydrology. Three such hillslopes have been identified in the Horse Draw subbasin of Piceance Creek and are illustrated in Figure 12c and d. These hillslope models would allow for discerning among sediment produced naturally from the hillslope, the influence of roads only on sediment production, and the influence of well-pads and roads on the production of sediment.

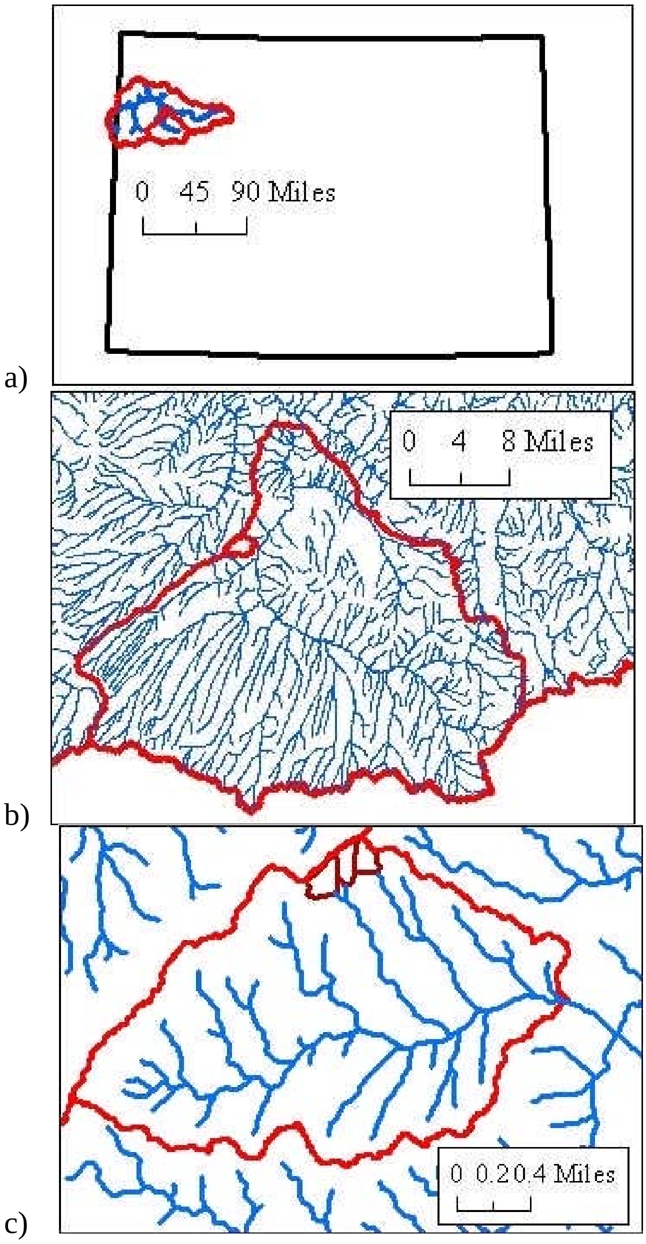

Figure 12: Spatial boundaries of areas to be modeled are a) The White River and Piceance watersheds, b) the Piceance Creek and Horse Draw watersheds, c) the Horse Draw watershed and 3 hillslopes of the watershed, and d) the 3 hillslopes within the Horse Draw watershed underlain by an aerial photo of the area.

d)

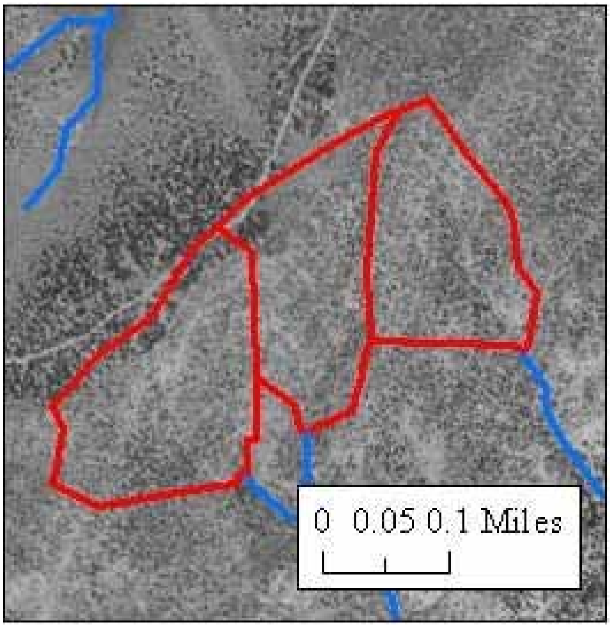

Figure 12-continued: Spatial boundaries of areas to be modeled are a) The White River and Piceance watersheds, b) the Piceance Creek and Horse Draw watersheds, c) the Horse Draw watershed and 3 hillslopes of the watershed, and d) the 3 hillslopes within the Horse Draw watershed underlain by an aerial photo of the area.

According to Yapo and others (1996), to adequately calibrate and validate a watershed model, 8 years of temporal data are needed for both the calibration and validation. Shorter periods can fail to capture the interannual climatic variation that occurs. As the long-term effects of energy development on environmental health are desired, it is necessary that the models developed account for the varied conditions the system will experience. For watershed models like Soil Water Assessment Tool (SWAT), the most common form of calibration data is streamflow measured at the outlet of the watershed being modeled. As Table 15 indicates, there is enough data available at both the White River and Piceance Creek stream gages to allow for calibration and validation periods.

Table 15: Stream gage information for monitoring sites on the White River and at outlet of the Piceance Creek.

Gage	Period of Record	Drainage Area (mi^2)	Mean annual Discharge (cfs)	Mean annual Discharge (inches)
White River near Watson, UT	04/01/1923 - Present	4,020	690.4	2.33
Piceance Creek at White River, CO	10/01/1964 - Present	652	35.6	0.74

Ideally the models developed for each watershed would use the same time periods for the calibration and validation periods. The calibration period does not have to precede the validation period because it is assumed each period encompasses the same variability. Because there is daily suspended sediment data available at the Piceance stream gage during the period from 4/1/1974-9/30/1982, this period will be used to calibrate the models. The benefit of using this period for calibration is that the models can be calibrated to streamflow and sediment yield. No data exists from a prior period to examine erosion from hillslopes, which is why the three hillslope approach would be used; they would represent pristine and altered states. The temporal boundary for the WEPP model consequently would be the length of the monitoring project.

Task 4: Developing a general mass balance for the system to be modeled allows the scientist doing the modeling a chance to become familiar with the area and the potential environmental processes at work. In addition, a general mass balance provides some general conditions with which to evaluate initial model performance. For the modeling within the White River and Piceance Creek watersheds, estimates of the water balance would be obtained. Values of long-term, mean annual values of precipitation, streamflow, and evapotranspiration could constitute a coarse water balance and are readily attainable from Internet based geodatabases and literature sources. Precipitation data can be obtained from numerous weather stations in and around the White River watershed using the NWS website listed above. Using data from 9 stations and with a minimum period or record of 18 years and a maximum of 64 years, a mean annual value of 13.7 inches of precipitation was derived. Mean annual estimates of streamflow can be obtained from the USGS website listed above. Using those sources, the mean annual values for streamflow from both watersheds were obtained and are presented in Table 15. Evapotranspiration losses are the hardest to estimate and although estimates of actual evapotranspiration are available in some places, estimates are generally obtained by adjusting estimates of potential evapotranspiration (PET) or through using literature sources. For Piceance Creek, two water balances were obtained from available literature. The BLM (2006) and Wymore (1974) each developed mean annual water balances for the Piceance Creek watershed. A summary of the published mass balances and the precipitation and streamflow estimates described above is presented in Table 16.

Table 16: Comparison of mass balance values presented by Wymore (1974), the BLM (2006), and those obtained via the Internet.

	Piceance Creek		
Inches	Wymore	BLM	Online
Precipitation	13.89	15.5	13.74
Streamflow	0.39[a]	0.74[b]	0.74
Evapotranspiration	17.01	42.5[c]	

a. Presented as a summation of streamflow and percolation.
b. Presented as minimums and maximums, but used the same data as that collected online.
c. Presented as 40-45 inches and is an estimate of PET rather than actual evapotranspiration.

Task 5: Using the mass balance and field observations it is possible to arrive at a general conceptual understanding of the environmental processes occurring. An example of how this might be accomplished will be presented that considers that data available for Picenace Creek. From the mass balance it is apparent that evapotranspiration exceeds precipitation on an annual basis. Intuitively then, contributions to streamflow from groundwater must be important because the water flows perennially (Figure 13). From the day to day variability in the daily hydrograph, however it is evident that quicker flow paths exist. The lack of correlation between precipitation and streamflow, which is indicative of surface runoff that occurs when precipitation rates exceed the infiltration rate of the soil (Hortonian flow), suggests that hydrograph peaks are caused by shallow subsurface pathways (Figure 13). As a result of the freeze/thaw action occurring in the area throughout the winter more of the snowmelt would infiltrate taking a more circuitous route to the stream than if it were to travel directly over the surface. The sediment data can also be used to help develop the conceptual understanding of the environmental processes. When comparing the observed suspended sediment and streamflow data, as in Figure 13, it is apparent that increases in suspended sediment generally correspond to increases in streamflow. Intuitively erosion occurs at the surface. For erosion to occur then it follows that surface runoff must also occur. Because of the lack of correlation between precipitation and streamflow and the occurrence of erosion it is probable that surface runoff is occurring through a saturation excess process. Saturation excess runoff occurs when the soil becomes saturated such that any further received precipitation is unable to infiltrate and must run over the surface. This conclusion has further implications in that it can be assumed that the area of the watershed contributing sediment to the streams corresponds to areas that reach saturation following a precipitation event. Generally these areas are in relative proximity to the stream. It should be noted that although this example may represent the hydrologic processes occurring it is provided more as a demonstration as to what the modeler should consider when developing a conceptual hydrology.

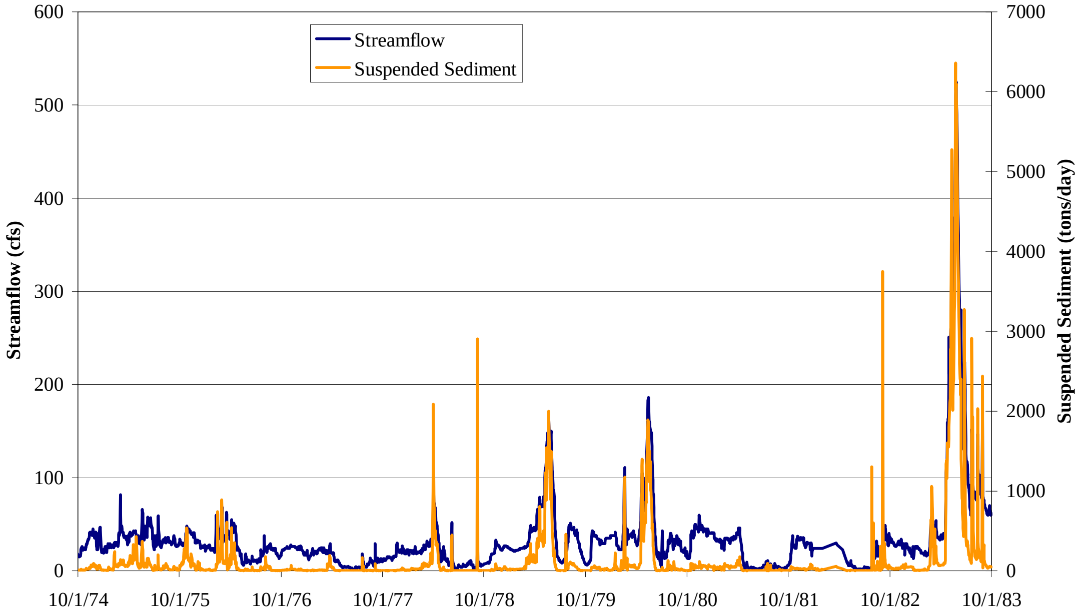

Figure 13: Mean Daily Streamflow and Suspended Sediment Observed at Piceance Creek at White River from October 1, 1974 through September 30, 1983.

Task 6: Although several models exist to simulate erosion processes at a hillslope and watershed scale, few are able to reproduce the hydrologic processes governing streamflow production. Two potential models able simulate such processes are the Water Erosion Prediction Project (WEPP) model (Flanagan and Livingston, 1995) and the Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1995). The WEPP model represents the most contemporary, physically based model for simulating erosion processes for watersheds and their hillslopes. It was designed to replace the Universal Soil Loss Equation (USLE)(Wischmeier and Smith, 1978) as the preferred method for estimating erosion. Use of the WEPP model "is limited to areas where the hydrology is dominated by Hortonian overland flow" (NSERL, 1995). This fact is a concern given the conceptual hydrology described previously. In contrast, the SWAT model can account for hydrologic processes other than streamflow produced from Hortonian flow and has been applied to watersheds across the world. The SWAT model uses the USLE method to simulate erosion at scales varying from entire watersheds to Hydrologic Response Units (HRUs). Within SWAT, HRUs are meant to represent areas with dominant soils and landuse and are not explicitly attributable to a specific area within a watershed. Advantages to both models are that they have friendly Graphical User Interfaces, detailed tutorials, and the software and required data are available Online for free.

When the models identified are potentially unable to adequately answer the scientific questions being asked, as in the example above, it is common to use multiple models to achieve the desired results. With this in mind it is reasonable to use the WEPP model to simulate the specific hilllslope erosion processes of each of the three hillslopes of Horse Draw. The SWAT model would be used to simulate the erosion processes of the White River, Piceance Creek, and Horse Draw watersheds. Using this combination of models will allow the modeler to analyze the processes governing sediment transport from drainages with areas as small as 12.4 acres up to the 4,020 mi^2 of the White River. Modeling the Horse Draw subbasin with both models will add an aspect of quality control to the modeling when the simulated sediment production from each model is compared.

Task 7: Creating the models requires intimate knowledge of the (1) geospatial and temporal data available, (2) preprocessors used to convert data to the format used by the model, (3) physics of the potential environmental processes and how the model accounts for them, (4) methods of sensitivity analysis, (5) and methods of calibration and validation. Because the SWAT and WEPP models will be designed to simulate sediment yields seasonally and annually it is not necessary to ensure the daily climatic spatial variability is explicitly accounted for in the model. The coarse time scale also allows the modeler to use weather generators that are available with each model, although the simulated climate should be compared to climate data available from stations in around the basin to ensure consistency.

Becoming familiar with a preprocessor can take a considerable amount of time, on the order of weeks to months. Although the details of the preprocessors used for SWAT and WEPP are too numerous to recount in this document, both require experience with manipulating spatial data using a Geographic Information System. Fortunately, tools are available with each model to obtain the required spatial data, which limits errors that might occur due to incorrect formats.

To understand the theory behind the sediment transport processes simulated by SWAT and WEPP it is necessary that the modeler have a detailed understanding of the physics of erosion and hillslope and watershed hydrology before reading each models documentation. This knowledge is invaluable if the models are calibrated manually because the modeler will understand how different processes interact with each other and can logically adjust parameters. Additional knowledge of possible values for parameters, such as hydraulic conductivity, *a priori* can ensure model parameters are constrained within reasonable limits. Calibration of the models can be a very time consuming processes depending on the complexity of the hydrologic processes occurring and model being used. Models can have numerous parameters so it is common to conduct a sensitivity analysis to identify to what degree parameters influence a model. Often the sensitivity analysis is automated. Through extensive use of the model, literature reviews and a conceptual understanding of the environmental processes, though, the most sensitive parameters can often be identified. Following the sensitivity analysis the models could be either manually or automatically calibrated. Manual calibrations can be laborious, especially if the modeler is unfamiliar with the models sensitive parameters. The benefit of manual calibration is that the scientist becomes very confident with the workings of the models, the system being modeled, and the results produced by the models. Automatic calibration can decrease the time required to identify sensitive parameters and calibrate the model. It is essential that the scientist be very familiar with the mathematical and statistical manipulations used by an automatic method of calibration to avoid the acceptance of parameter sets that may inadequately represent the environmental processes occurring. Both calibration and validation are discussed in more detail by Beven (2001) and Abbott and Refsgaard (1996).

Tasks 8-10: From the modeling experience gained so far it may be apparent that either the conceptual understanding of environmental processes occurring was flawed, or the models did not perform as hoped, or there was insufficient data to adequately examine the processes occurring. It should be apparent to the modeler what environmental parameters are sensitive in the system and, correspondingly, what monitoring should be introduced or enhanced to improve model performance. Upon realizing what adjustments are required, the modeler should coordinate with resource managers so that they are aware of what is needed to best use the modeling tools.

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