Conceptual Framework and Protocols for Conducting Multiple Scale Aquatic, Riparian, and Wetland Ecological Assessments

for the

USDA Forest Service – Rocky Mountain Region

Report 1 of 2

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We would like to thank Marisue Hilliard and Dave Anderson for their willingness to support a new way of doing business; the Regional Leadership Team for supporting this idea; the Species Conservation Team for developing the process; the fisheries biologists, hydrologists, and other specialists in the Region for being receptive to this process and for their input; our University colleagues for valuable input into developing the process; and the Forest Service Team members for going way beyond the call of duty.

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EXECUTIVE SUMMARY

The Rocky Mountain Region of the U.S. Forest Service (Region 2) has recognized the need to improve implementation of certain National Forest Management Act of 1976 (NFMA) requirements that relate to maintenance of *biological diversity, population viability, and ecological sustainability*. In the most general sense, departmental and agency regulations stemming from the Act require the Forest Service to maintain viable populations of existing native and desired non-native plant and animal species on National Forests and Grasslands (36 CFR 219.19 and USDA Department Regulation 9500-4). Meeting these requirements demands sophisticated land management across broad landscapes and over long time periods.

The Species Conservation Program was approved by the Regional Leadership Team to develop a comprehensive and coordinated approach to species conservation and ecological sustainability, which includes three elements: ecosystem assessments, species assessments, and conservation strategies or "synthesis tools" necessary to meet NFMA requirements. This program is a regional process designed to assure a thorough evaluation of appropriate ecosystems, species, and population viability in Forest Planning at appropriate temporal and spatial scales. The goal is to incorporate species and ecosystem conservation evaluation into planning and program development so that species conservation is accomplished in an efficient, proactive, and cost effective way. The program development emphasis of the aquatic, riparian, and wetland assessment process identifies the need for a proactive, long-term approach to species and ecosystem management. A goal of this approach is to aid Forests and Grasslands in identifying potential restoration and protection areas for important ecological conditions and species.

This document outlines the conceptual model and protocol used to assess aquatic, riparian, and wetland ecosystems at multiple scales. An accompanying document outlines the methodologies to be used to address anthropogenic activities. An understanding of the aquatic, riparian, and wetland ecosystem structure, composition, function and influence from management is critical to designing effective species and ecosystem conservation approaches. This protocol provides specific guidance that ensures the techniques and methods used to meet the goal of the assessments are acceptable and defensible from a scientific and management standpoint.

A team of scientists and resource specialists from Colorado State University, University of Wyoming, and the U.S. Forest Service developed the process. This collaborative effort included experts in the fields of aquatic biology, fishery biology, hydrology, fluvial geomorphology, wetland ecology, rangeland management, and geographic information science. A conceptual model to define the physical, biological, and ecological characteristics for aquatic, riparian, and wetland ecosystems has been developed using an ecological driver concept. Watershed sensitivity and importance is addressed in the protocol by defining wetland and riparian communities, sediment dynamics, fishery resources, and aquatic production at the basin, landscape, and management scales. Analysis of watersheds based upon anthropogenic influences (e.g., road density) is also defined in the protocol. The protocol has included internal and external peer reviews and field validation.

Lastly, this process is dynamic and only through an organized adaptive process can it be expected to be applicable to management needs in the future. This protocol will help the U.S. Forest Service design future inventory, monitoring, and research programs, and to detect changes in terrestrial and aquatic ecosystem condition that are relevant to species conservation concerns within the Rocky Mountain Region.

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CHAPTER 1
INTRODUCTION

Purpose and Overview

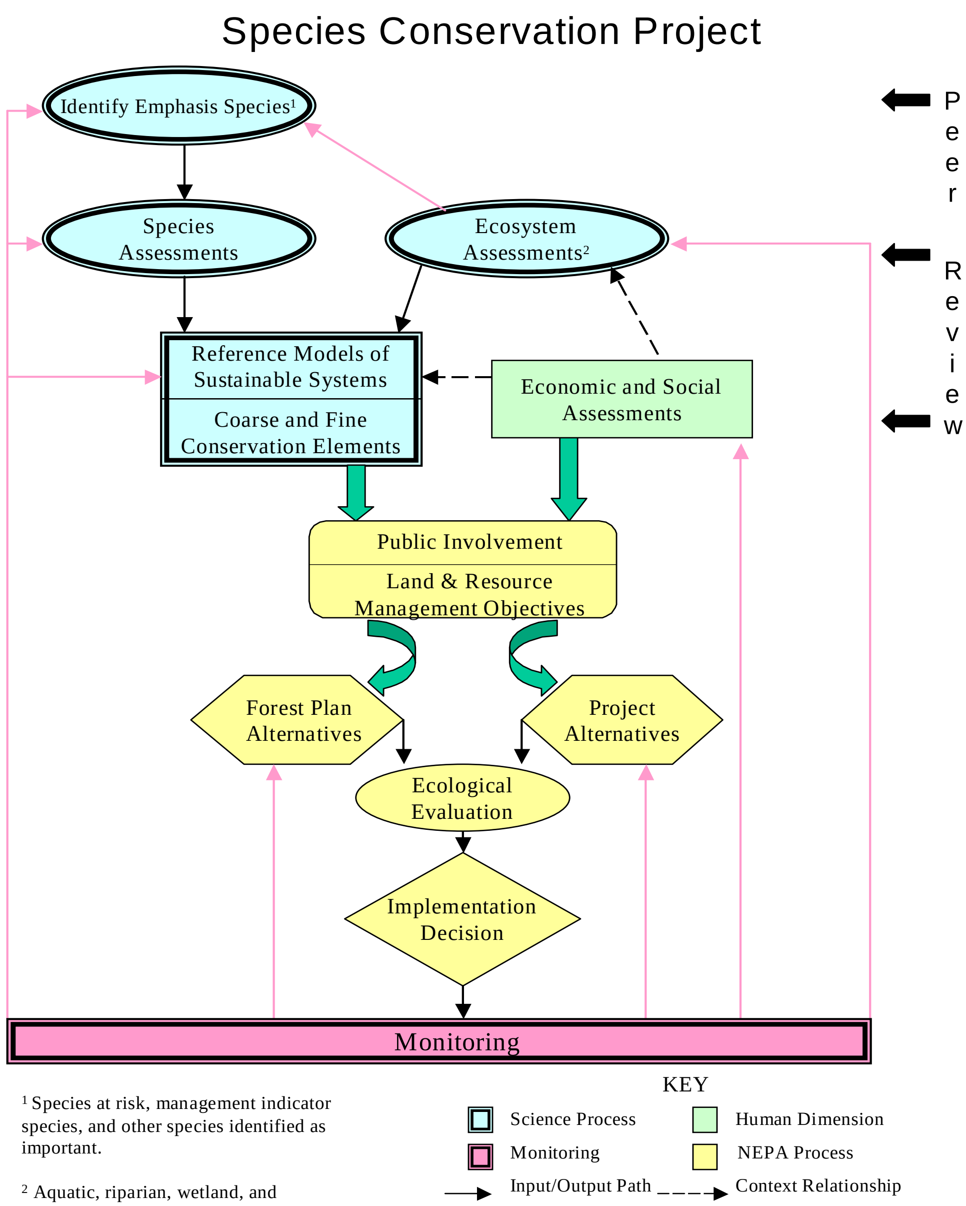
The purpose of this document is to describe the considerations and procedures necessary to conduct multiple scale aquatic, riparian, and wetland ecological assessments (ARWA) for mountain and grassland landscapes that occur within the Rocky Mountain Region (Region 2) of the U. S. Forest Service (USFS).

This protocol has been developed in response to direction from the Regional Forester and Regional Leadership Team to increase the quality and defensibility of resource management decisions related to species viability and ecological sustainability, as outlined in the National Forest Management Act of 1976. ARWA documents are intended to be used for planning and program development purposes at the Regional, Forest, and District level.

The Forest Service is directed to manage multiple-use activities over an extensive geographic area. The purpose of the ARWA protocol is to facilitate sound resource management on lands managed by the Forest Service as well as to influence management decisions on adjacent lands. Decisions based on utilizing this information are intended to maintain and improve ecological integrity of aquatic, riparian, and wetland ecosystems and to encourage the viability of organisms that are wholly or partially dependent on these ecosystems. In addition, the information derived from these assessments will be used in conjunction with species-specific assessments. The relationship between species needs and ecosystem characteristics are intended to facilitate decisions at the project scale that result in the integrity of ecosystems and the persistence of target species.

In 1998, a team of ecologists and biologists from Region 2 was charged with developing a process to improve land-management planning in the context of species conservation and ecological sustainability. This team, referred to as the "Species Conservation Team," developed the process currently used in Region 2 (Fig. 1.1). Multiple scale species-specific assessments, as well as ecological assessments, are being developed for use in Region 2, which ultimately will be used to develop conservation strategies and other tools for the management of species and ecosystems.

Region 2 comprises over 20 million acres of diverse mountain and grassland environments (Fig. 1.2). The region is divided into a total of twelve main administrative boundaries (National Forests and Grasslands) that often bisect ecological units or river basins. Typically, species viability analyses and ecological sustainability have been conducted within individual administrative boundaries, resulting in inconsistencies in management direction and management decisions. For example, fen communities might be relatively abundant in a particular National Forest, and may not be considered a resource that warrants management priority. However, throughout their existing range, in the Rocky Mountains or nationwide, fens are a rare and important ecosystem.



[1] Species at risk, management indicator species, and other species identified as important.

[2] Aquatic, riparian, wetland, and terrestrial.

Figure 1.1. Conceptual model for the Species Conservation Project.

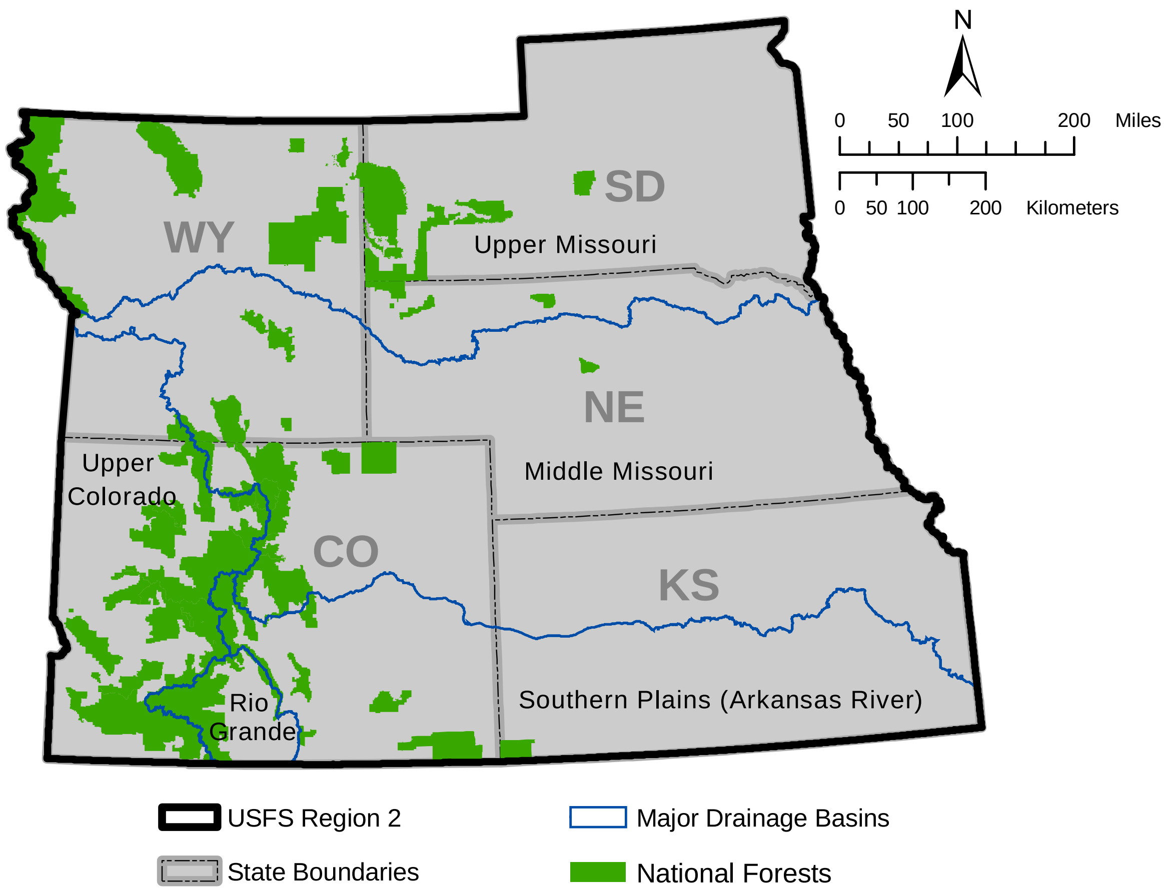


Figure 1.2. Region 2 of the USDA Forest Service with major river basins identified.

The protocols developed for conducting assessments are cornerstones of the planning process. They provide the user with guiding principles that are useful for understanding many of the aspects of conducting ecological assessments in conjunction with planning and project implementation process. Therefore, the protocols reflect well-documented and scientifically credible methodologies. The protocols are based on current ecological knowledge and are subject to peer review, management review, and stakeholders input, and are intended to be adaptive in response to new information. The protocols were carefully developed and documented, and will help facilitate the work done by forest planners, natural resource managers, and ecologists. Also, they will lend great credibility to program development and ultimately management decisions.

This multiple scale assessment protocol is critical in ecosystem assessments and will integrate into virtually all subsequent activities in the planning process, including species assessments and the development of conservation strategies. The following criteria summarizes the ARWA protocol document:

(1) It provides background, justification, and rationale for the development of a multiple scale assessment process. It emphasizes ecosystem level organization and uniformity of approach both temporally and spatially. The result is a well-documented process that is defensible and lead to consistency throughout Region 2.
(2) It creates a multiple analytical framework for assessment and classification at multiple scales with an emphasis on statistical and sampling associations and hierarchical approaches. The framework will be used to assess factors or ecological

drivers of ecosystem structure and function.

(3) It produces a systematic and spatially determined (mapped) process to identify the sensitivity of ecosystem units to past and present management activities so that conservation areas, areas at high and low risk of anthropogenic disturbances, and areas already impacted by human activities, can be described.

(4) It identifies questions to be answered by a properly implemented assessment for Forest management purposes.

U.S. Forest Service Planning Process

Legal Framework & Current Status

The National Forest Management Act (NFMA) of 1976 provides the mandate for conducting multiple scale ecological assessments on Forest Service lands. NFMA states that it shall be the Forest Service's responsibility to "provide for diversity of plant and animal communities based on the suitability and capability of the specific land area in order to meet overall multiple-use objectives." The NFMA further provides that "fish and wildlife habitat shall be managed to maintain viable populations of existing native and desired non-native vertebrate species in the planning area."

In order to accomplish the objectives in the NFMA regulations, it is imperative that we understand the natural ecological processes and human influences that determine the structure of biological communities.

In 1969, the National Environmental Policy Act (NEPA) was enacted to ensure that all federal lands be managed to "encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; (and) to enrich understanding of the ecological systems and natural resources important to the nation" (Jensen and Bourgeron 2001). This balance between ecological sustainability and human influence presents challenges for federal resource managers who are responsible for managing these two components given increased resource demands and public scrutiny of management actions.

Beginning in the 1960s, several environmental laws were enacted that clearly expressed the intent of Congress and the public to protect non-commodity resources such as wildlife and fish, wilderness, clean water and air, recreation and aesthetic values (Dombeck et al. 1997). The Clean Water Act, Clean Air Act, Wilderness Act, Endangered Species Act, Wild and Scenic Rivers Act, and other federal and state legislation were enacted during this time, in part to ensure ecological integrity and species diversity.

Role of Multiple Scale ARWA Protocols in Planning Process

Multiple scale assessments provide the spatial and temporal information necessary to understand ecological form and function and provide tools necessary for land managers to make sound resource management decisions addressed in the legislation discussed previously. However, it is important to understand that ecological assessments are not decision documents because they do not resolve issues or provide direct solutions to specific policy questions (Jensen and Bourgeron 2001). Multiple scale ecological assessments should:

(1) Synthesize existing information and present conclusions about the status, trends, spatial patterns, and relationships of ecosystems and species.

(2) Identify interrelationships among human land use, species diversity, ecosystem health, and disturbance processes as well as the biophysical capabilities of the landscape.

(3) Provide key information that help identify potential reference and restoration watersheds.

Ecosystem and species diversity contribute to ecological sustainability (Foose et al. 1995; Ulanowicz 2000). Assessments therefore must include information on these topics at several spatial and temporal scales, including geographic scales such as bioregions and watersheds, scales of biological organization such as communities and species and scales of time ranging from months to centuries.

Ecological assessments need to include descriptions of the biological and physical characteristics of each ecosystem as well as the principal ecological processes that influence ecosystem structure and composition in the analysis area. Such descriptions should include the distribution, intensity and frequency of natural disturbances during the current climatic regime and other ecological processes important to ecosystem sustainability. Moreover, the descriptions should discuss the role of anthropogenic disturbance in the long-term ecological sustainability of the area.

Ecological assessments have received considerable attention in the last decade, due in large part to efforts in other parts of the country (Northern Forests Land Council 1990; SAMAB 1996; Quigley et al. 1997). There have also been several books and manuscripts that document procedures and the required information for preparing ecological assessments (Bailey 1996; Jensen and Bourgeron 2001). Our objective was to use these earlier assessments to develop a process and the assessment protocols for the Rocky Mountain Region of the Forest Service.

Aquatic, Riparian, and Wetland Assessment (ARWA) Model

A conceptual model of the ARWA process was developed to identify the effects of current and historic anthropogenic influences on ecosystems associated with lands managed by the U.S. Forest Service and determine their relationships to the ecological drivers that influence aquatic, riparian, and wetland resources (Fig. 1.3). In order to describe the components of this model, each major topic, such as ecological drivers and anthropogenic influences, is addressed as a separate chapter. It is important to note, however, that these components are to be incorporated synergistically to help managers understand the relationship between ecological processes and aquatic, riparian, and wetland resources, landscape sensitivity, and risk from anthropogenic influences. In addition, areas characterized by extensive anthropogenic impacts and unimpacted areas will be identified. This information can be used to address in part, the following questions:

(1) Where would the highest concentrations of wetlands and riparian areas be expected?
(2) What is the range of watershed sensitivity to anthropogenic influences?
(3) Which watersheds contain the characteristics and levels of anthropogenic influences important for the reintroduction of native species?
(4) Which watersheds have characteristics most important for fisheries and aquatic production?
(5) Which watersheds are most sensitive in terms of potential sediment production?

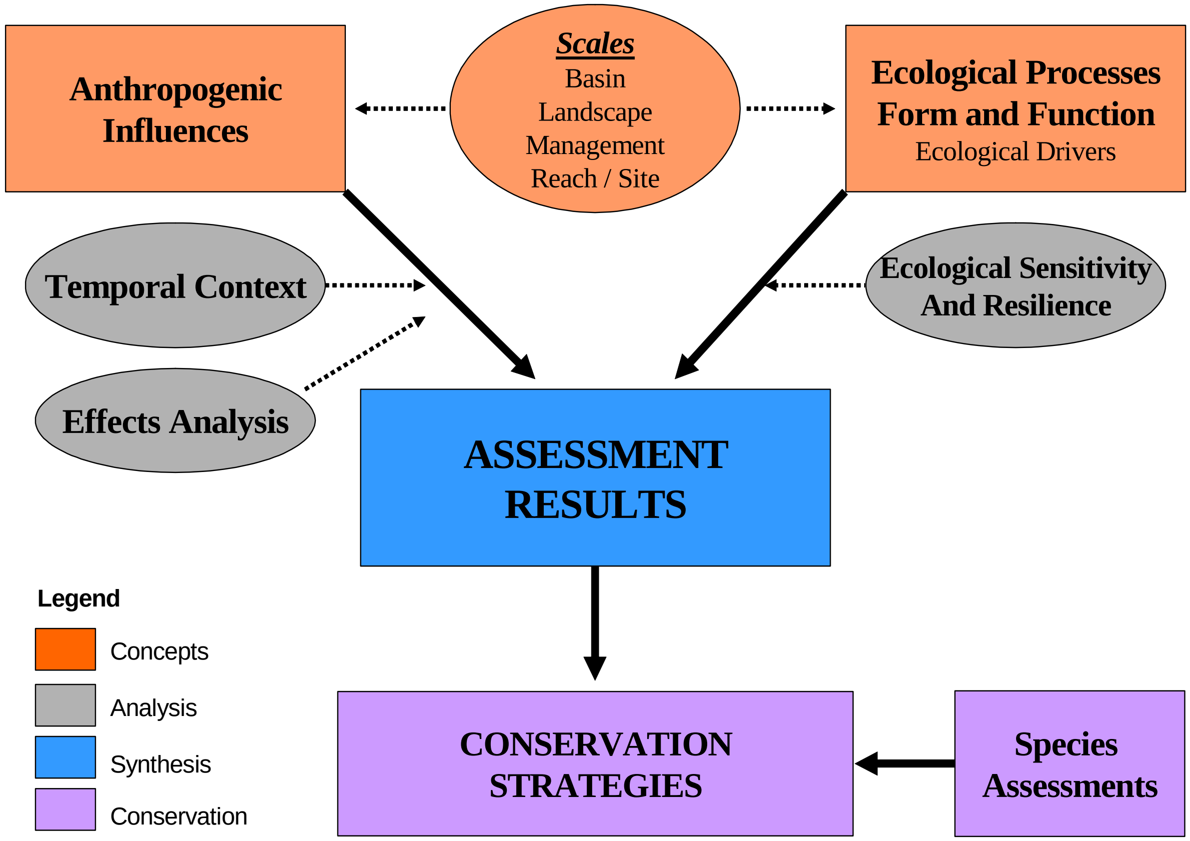


Figure 1.3. Conceptual model of the aquatic, riparian, and wetland assessment process.

Implementation Schedule

The completion of multiple scale aquatic, riparian and wetland assessments for the major river basins in the Rocky Mountain Region of the Forest Service will provide the basis for future planning and project evaluation in several ways. By addressing aquatic, riparian, and wetland resources and anthropogenic influences in a more consistent fashion across the Region, we will meet the requirements of federal mandates such as the National Forest Management Act, Clean Water Act, and the Endangered Species Act with a much higher level of quality and defensibility. The needs of imperiled species and environments will also be addressed more consistently and with a higher level of confidence that meets citizen's demands. While individual assessments may not be finalized prior to Forest Plan revisions and project level planning, it is important to note that even portions of each assessment may be valuable for analysis. In addition, Forests and Grasslands may use portions that follow the protocols to meet immediate analysis needs.

The aquatic, riparian, and wetland assessment process will occur in two distinct phases (Fig. 1.4). The first phase defined the conceptual model and protocols for the assessment process and will conduct preliminary multiple scale assessments in identified areas of the Rocky Mountain Region of the Forest Service. The second phase includes the validation and adaptation of the process. This second portion is critical to provide defensibility to assumptions and results

The assessment process described is relatively complicated and data intensive. The ability to implement this process in a timely and cost effective manner across Region 2 of the USDA Forest Service will require managing time and personnel effectively. Through experience gained from conducting a "pilot" multiple scale assessment on the Bighorn National Forest, and direction from the Regional Leadership Team, a process for conducting these assessments has been developed (Fig. 1.5).

Phase I

Conceptual Framework and Protocol Development
for the Rocky Mountain Region

↓

Assessment Completion
at the Basin, Landscape, and Management Levels

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Phase II

Validation of Model
with Fine Scale Measurements

↓

Adaptation of Process
with Validation

Figure 1.4. The two phased approach used in the aquatic, riparian, and wetland assessment protocol.

The Region 2 Leadership Team determined that the most cost and resource efficient way to address aquatic, riparian, and wetland assessments is to have a team of University and Forest Service scientists collaborate in the process. The University faculty will address the ecological driver portion of the assessments, and the scientists from the individual National Forests and/or Grasslands will conduct the analysis on the anthropogenic influences. Regional Office scientists will assist both teams, and oversee the project from a consistency and defensibility standpoint.

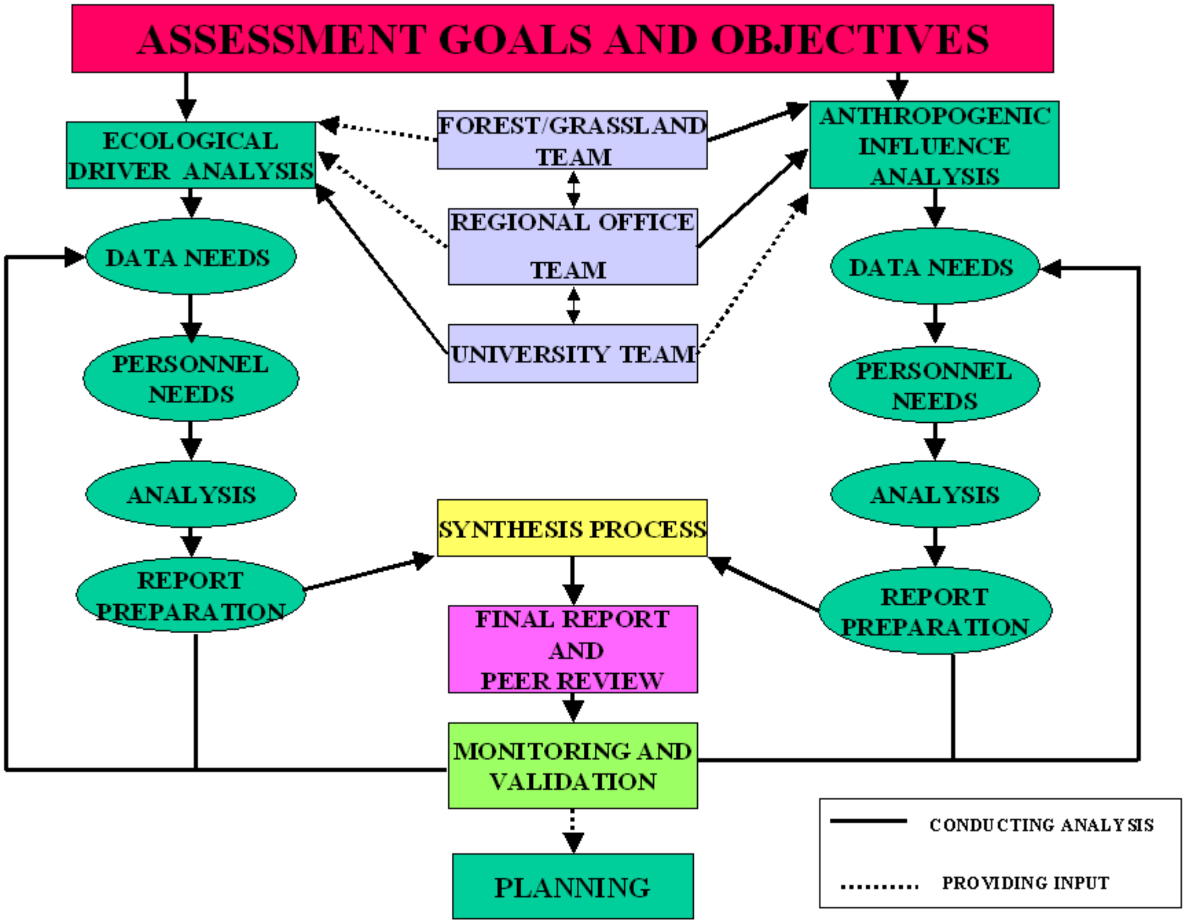


Figure 1.5. Flowchart of implementation steps for the aquatic, riparian, and wetland assessment process.

Information or data needs should be the first topic of discussion between the teams (Fig. 1.5). Forest and Grasslands scientists and University team members, as well as Regional Office personnel, should be part of this collaboration. The availability of geographic information (GIS) and historical literature is critical in determining personnel needs for the process.

Step 2 of the process is to identify personnel and funding needs to accomplish the assessment analysis, writing, and synthesis (Fig. 1.5). The GIS expertise can be extremely limiting in certain Forests, yet this expertise is vital to the success of the process. In addition, a competent writer/editor is also important to getting the assessment completed. The tasks assigned to all the scientists (both Forest Service and University) require extended blocks of time to complete. Assignments should be scheduled, agreed upon, and adhered to if time frames and costs are to be met.

Analysis and report preparation for both the anthropogenic influence analysis and the ecological driver analysis are the 3rd and 4th steps (Fig. 1.5). Consistency and defensibility is an important part of this effort. Personnel that are experienced in scientific writing, researching literature, and problem solving should be identified for this effort. Commitment to report preparation, both in terms of time and expertise is critical for producing a document that will be a valuable resource for the management of aquatic, riparian, and wetland resources.

The portion of the assessment we term the "Synthesis Process" is probably the most important part. The success of this process relies on several important factors including:

(1) The thoroughness of completing the previous steps.
(2) Structuring the synthesis process to address specific questions related to management.
(3) Strong and committed leadership to bring the teams together to develop sound results.
(4) Follow up on the decisions made so they are included into the final assessment.
(5) Focus on the ecological components and needs of aquatic, riparian, and wetland resources, and not the social aspects of the future planning process.

The final assessment should be complete when there is agreement from both teams on the components and synthesis of the aquatic, riparian, and wetland information.

The final step of the aquatic, riparian, and wetland assessment process is the monitoring, validation, and adaptation portion (Fig. 1.5). Multiple scale assessments of this type on U.S. Forest Service lands are a relatively new way of assessing ecosystems, and therefore they need to be updated and improved when data gaps are identified and filled. Consideration should be made to validate the assumptions made and refine the process both during the analysis phase and following the assessment process. Monitoring and validation questions should correspond to budget cycles to ensure that the assessments do not become obsolete.

Process for Validation and Evaluation

Development of a protocol at multiple scales primarily serves to stratify a forest into units of "similar" physico-chemical drivers of known ecological relevance. The validation and evaluation of this protocol requires two separate steps: physical validation and biological validation.

Physical Validation

The validation of the physical characteristics of stream channels predicted to drive ecological condition is based on assessing whether actual hillslope and channel characteristics match those predicted using the driver combinations outlined in this protocol. There are two steps to such an evaluation. The first step of the physical validation is to determine whether the predicted associations among hillslopes, channel forms, and channel processes and physico-chemical drivers do in fact occur. For example, in the Bighorn National Forest areas with calcareous rocks, snow-driven precipitation, and high gradient stream environments are predicted to produce step-pool channels that are straight, have cobble and boulder substrates, coarse sediment input from hillslope failures, and a seasonally stable in-channel sediment transport regime. A simple visual assessment of field sites can be used to verify whether these predicted characteristics occur together.

The second step of the physical validation involves determining whether the boundaries of driver combinations as mapped using available data match the actual boundaries of these combinations present in the field. Again, field-based site visits can be used to compare mapped boundaries to actual boundaries.

Biological Validation

The biological validation can be undertaken in two ways, depending on the types of biological data that can be collected. First, at the 6th level Hydrologic Unit Boundary (HUB) or management scale, it may be possible to identify certain continuous biological coverages, such as wetland or riparian community types. Such data could be used to test the predictive capability of the 6th level HUB protocol. Cluster analysis is recommended to identify groups of HUBs that have similar driver combinations. For each HUB, the area, or percent area, of each wetland or riparian community type is then determined. Mean area (and variance) or percent wetland area or riparian type in HUBs located within each cluster group is then summarized in tabular form. The clusters can be statistically compared using Analysis of Variance or other tests, to determine whether the clusters, based upon physical drivers, are useful predictors of the distribution and abundance of wetland and riparian ecosystems.

Many types of biological data of interest in the ARWA cannot be collected as continuous coverage data; rather, they must be collected as "point" samples through some kind of random sub-sampling process for an entire forest. Accordingly, biological data will need to be collected from individual stream reaches, meaning a second phase is required to actually validate the management scale protocol.

In Phase II, reach/site scale drivers will be identified, quantified, and applied to develop the basis for a reach/site scale protocol. Biological data at the reach/site scale (e.g., for fish or invertebrate diversity) can be collected from a variety of habitat types and used to validate both the protocol at the reach/site scale and the 6th level HUB. Because these data will be collected in a hierarchical framework (stratified reaches within stratified 6th level HUBs), statistical analyses can be conducted to evaluate the independent (and co-varying) explanatory power of drivers at the reach/site scale and 6th level HUB drivers. The validation of the ecological effects of anthropogenic alteration is conducted at the reach/site scale in a similar nested fashion. After validating the reach/site scale protocol, aggregation of constituent reach types within 6th level HUBs will allow the management unit to be characterized in terms of resource condition. This validation process is inherently adaptive, because it allows refinement of the present 6th level HUB classification, based on new biological data.

Document Organization

This document is organized to demonstrate the importance of conducting analysis at multiple temporal and spatial scales. In addition, we explain how we developed the process of utilizing landscape characters or “drivers” to understand aquatic, riparian, and wetland form and function exclusive of the influence of human management.

Chapter 2 describes the hydrologic-unit based hierarchical framework for the ARWA protocol. The ecological characteristics of aquatic, riparian, and wetland ecosystems and the important spatial scales used in the multiple scale ARWA protocol are outlined in Chapter 3. Chapter 4 explains the cluster analysis that we propose as a method to assess the aquatic, riparian, and wetland ecosystems by evaluating different driver combinations. Chapter 5 addresses anthropogenic and management influences. The synthesis of ecological driver results and the anthropogenic influence analysis is described in Chapter 6.

A companion document *Anthropogenic Influences used in Conducting Multiple Scale Aquatic, Riparian, and Wetland Ecological Assessments* identifies anthropogenic activities that should be considered when conducting aquatic, riparian, and wetland assessments. This document focuses on the relevance of an anthropogenic activity to management effects on aquatic, riparian, and wetland resources, and suggests how they can be measured at various scales.

CHAPTER 2
INFORMATION MANAGEMENT FRAMEWORK AND ECOSYSTEM DELINEATION

Introduction

Multiple scale assessments require assembling, analyzing, and integrating information about biotic and abiotic landscape features across large geographic areas. Assessments are conducted at multiple scales in order to reflect ecosystem-wide influences on conditions within a single administrative unit (NFMA Planning Rule Assessments Working Paper unpublished). Both terrestrial and aquatic ecosystem patterns and processes display heterogeneity at a variety of spatial levels (Turner and Johnson 2001), necessitating that ecological characterizations and assessments assume a multi-scaled, hierarchical approach.

Ecosystem unit mapping is a key component of ecological assessments (Bailey 1996; Rowe 1996). Assuming that ecosystems can be characterized at different scales (hierarchically arranged), ecosystem *units* can also be arranged in a hierarchy of sizes, facilitating the capture of links between biotic and abiotic ecosystem components, and links between terrestrial and aquatic systems (Bourgeron et al. 2001a). This chapter outlines the hydrologic-unit based hierarchical framework for the ARWA protocol. This description is prefaced by a review of the current USFS Region 2 information management strategy for water resources data.

USFS Information Management

The Forest Service collects and analyzes data to help make decisions about the most efficient way to manage resources on our National Forests. USFS information infrastructures, which support the capture, management, and analysis of water resources data, may be grouped into three broad categories: (1) aquatic inventory; (2) aquatic ecological classification; and (3) watershed assessment.

Aquatic inventory procedures primarily address data collection at the channel unit, stream reach, and valley segment levels of the hierarchy of aquatic ecological units.

Aquatic ecological characterization procedures address the evaluation of data and characterizing streams, valleys, and/or riparian areas to discover or identify ecological types, again, mostly for channel units, stream reaches, and valley segments, but also at a watershed and area-wide (broad scale) level.

Over the last 25 years, the Rocky Mountain Region has expended considerable funds and effort in developing assessment and inventory approaches, with limited results (Fig. 2.1). Several reasons may be responsible for this trend, including inappropriate scales, lack of repeatability and defensibility, and the evolving nature of the science. In addition, a standardized data structure framework has been lacking to support these efforts. To address this issue, an agency-wide strategic information management plan has been evolving within the Forest Service in the last ten years. Within the Rocky Mountain Region, these efforts have centered on the synthesis of four major data products: Cartographic Feature Files, the Common Survey Data Structure (CSDS), the Integrated Data Solutions (IDS) database, and the Integrated Resource Inventory (IRI). The overall goal of this effort is to provide spatially referenced resource information for Forest Service administered lands in a standardized, integrated format.

Of the four data products listed above, the Integrated Resource Inventory (IRI) is the system designed for spatially locating, defining, and describing unique water, land, and vegetation characteristics across the landscape in the Rocky Mountain Region. The

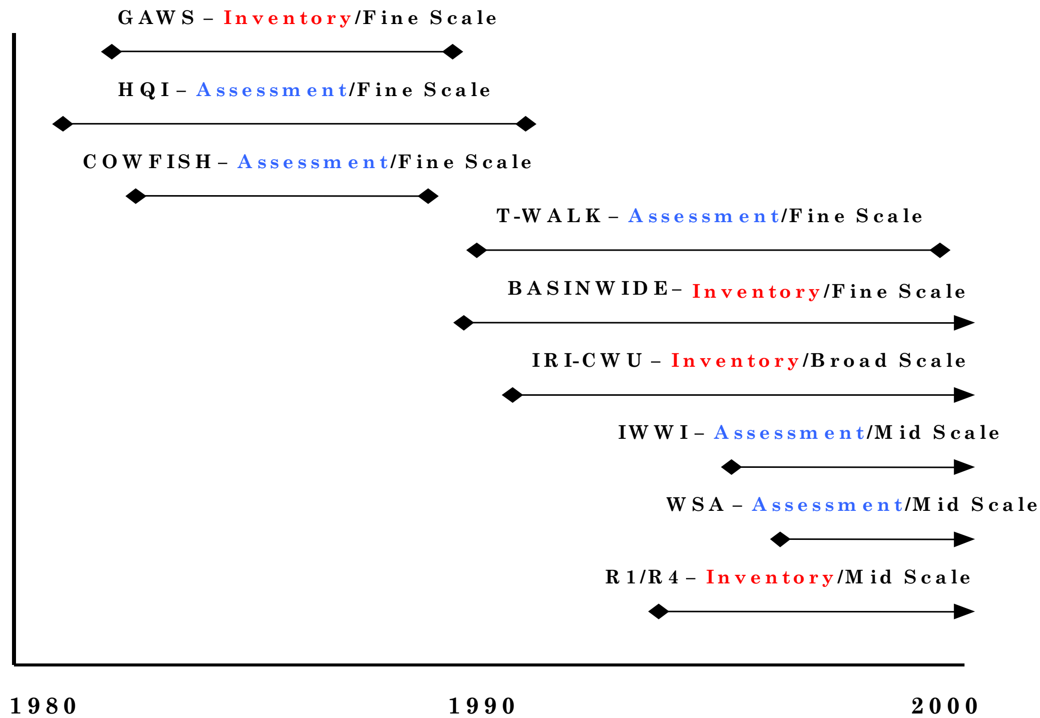


Figure 2.1. Assessment and inventory procedures utilized in Region 2 from 1980 to the present at various scales (e.g., fine to broad scale). Examples represent both regionally and nationally developed approaches: GAWS – General Aquatic Wildlife Survey; HQI – Habitat Quality Index; COWFISH – Cowfish; T-WALK - Thalweg Walk; BASINWIDE – Basinwide Stream Inventory; IRI-CWU - Integrated Resource Inventory-Common Water Unit; IWWI - Inland West Watershed Initiative; WSA - Watershed Assessment; andR1/R4 - Region 1,4 Stream Inventory Protocol.

The IRI is composed of the following three distinct theme databases organized within a geographic information system (GIS) environment: (1) Common Water Unit (CWU); (2) Common Land Unit (CLU); and (3) Common Vegetation Unit (CVU). The primary data layer for the CWU is a line-feature stream layer, while two unique polygon feature data layers define the CLUs and CVUs. All three layers are spatially referenced to 6th level hydrologic unit boundaries within a Forest Service administrative unit (IRI Training Guide 1995, 1-4,5). It is important to note that there is very limited information on riparian and wetland ecological form and function provided by these data sources. For example, in Chapter 3 the concept of "ecological drivers" or the major influences on aquatic, riparian, and wetland resources will be discussed. While these drivers are important to understand the extent and other characteristics of these resources, drivers such as glaciation, climatic conditions and stream temperature are not included in these databases.

IRI mapping is being undertaken at a 1:24,000 scale and utilizes the 6th level hydrologic unit boundary delineations as a common means of spatially cataloging information. Relative to the *National Hierarchical Framework of Aquatic Ecological Units* (Maxwell et al. 1995), the spatial scale of the CWU component of the IRI corresponds with the watershed and valley-segment riverine ecological units, the lake and lake-type lacustrine ecological units, and the groundwater region ground-water ecological units (IRI Training Guide 1995, 3-1,2). CLU and CVU components spatially correspond to the landtype and landtype phase levels of the *National Hierarchical Framework of*

Ecological Units (USDA Forest Service 1993; Cleland et al. 1997).

The Natural Resource Information System (NRIS) is the latest step in an agency-wide effort to synthesize and integrate the large number of distributed systems in use throughout the Forest Service for storing and analyzing natural resource information (including the IRI model adopted by the Rocky Mountain Region). The goal of NRIS is to merge all natural resource databases and information systems into six modules utilizing a common set of standardized base data, with an associated toolbox of analysis and output application tools to support field-level users in forest and grassland administrative units.

NRIS includes six thematic modules designed to take advantage of existing databases currently maintained by other agencies and cooperators: Air (quality and pollution impacts), Fauna (terrestrial wildlife), FSVeg (e.g., vegetation, esp. field sampled tree data), Human Dimensions (socioeconomic and demographic data), terra (soils, geology, geomorphology, etc.), and water.

The NRIS Water Module focuses on data about site level features associated with aquatic habitats and stream morphology, watershed level characterization and description, water rights and uses, and aquatic biota. Designed as a relational database/GIS application, it contains a set of analysis tools that includes maps, graphs, images, and related data about aquatic ecosystems, water uses and rights, and watershed improvement projects.

An important structural aspect of the NRIS Water Module is a hierarchy of aquatic ecological units (Maxwell et al. 1995), including:

(1) Multi-scale basin and watershed delineations based in part on U.S. Geological Survey and Natural Resource Conservation Service hydrologic unit code (HUC) delineations.[1]
(2) Valley segments (broad scale, landscape level subdivisions of the stream network)
(3) Stream reaches (groups of pools and riffles).
(4) Channel units (individual pools and riffles).

The NRIS Water Module currently consists of four sub-modules organized geographically by the nested hierarchy of the Hydrologic Unit Boundary (HUB) delineations. They include:

(1) <u>Aquatic Inventory (AI)</u>: supports "core attributes" reflecting three hierarchical levels of the riverine system – valley segments, stream reaches, and channel units. The core attributes describe national or Forest Service-wide data elements needed for the classification, mapping, and monitoring of aquatic ecosystems at multiple scales;
(2) <u>Aquatic Biota (AB)</u>: describes aquatic fauna communities in streams and lakes, providing users with the ability to identify and track miles of streams and acres of lakes occupied by threatened, endangered, and sensitive (TES) aquatic species;
(3) <u>Water Uses Tracking System (WUTS)</u>: tracks water uses and associated structures. Correlating water rights information to water uses provides the means to monitor the status of water rights administrative or judicial processes; and
(4) <u>Watershed Improvement Tracking (WIT)</u>: provides a means to inventory, plan, implement, and monitor watershed improvement projects either individually or at the watershed level.

Subsequent versions of the water module will address lakes and water quality needs as well as provide additional functionality in the current sub-modules. Watershed assessment and riparian assessment needs will be addressed through a collaborative effort with other modules (USDA Forest Service NRIS 2000).

The ARWA protocol conceptually addresses problems resulting from the often inconsistent and subjective nature of the numerous techniques used historically in the

[1] Original USGS and NRCS Hydrologic Unit Code (HUC) delineations are currently being revised nationwide using a newly drafted interagency standard for delineating hydrologic unit boundaries (HUBs) as part of the development of a National Watershed Boundary Dataset (WBD; FGDC 2002).

Region. While the protocol focuses on multiple scales larger than the reach/site level, it can also provide the framework for addressing consistent and defensible measurements at this finer scale as well. Subsequent planning and project level analysis would be more consistent and defensible throughout the Region, and specialists across administrative boundaries could utilize the extensive database developed across the Region.

Other USFS Data Products and Related Data Initiatives

Recently, the Forest Service adopted the National Hydrography Dataset (NHD) as its core GIS data standard for streams and water bodies.

The NRIS Water Module is being modified to incorporate the NHD spatial model as the basis for georeferencing data to streams and lakes. The 1:100,000-scale NHD is complete for the conterminous 48 states. In addition, plans are underway to develop a high density (1:24,000 scale) NHD stream network for all third-level hydrologic unit boundaries containing Forest Service lands (USDA Forest Service NRIS-Water 2000). Migration to the NHD will greatly facilitate cross-boundary, interagency planning, and management efforts.

Another USFS analytical tool, which may contribute to this effort, is the Inland West Water Initiative (USDA, Forest Service, unpublished Inland West Water Work Plan). This analytical tool uses qualitative assessment of geomorphic integrity, water quality integrity, biotic information, and watershed vulnerability at a sub-watershed level, as well as crucial and damaged stream segments, and dam and diversion presence or absence.

Due to its extremely generalized sampling schema, it is unlikely that the Inland West Water Initiative will prove useful in the initial assessment; however, the dataset could be utilized in subsequent coarse-filter validation efforts.

Ecosystem Hierarchy and the Development of a Hydrologic Unit-Based Assessment Framework

Ecological Scales

In order to assess the influence of appropriate environmental factors on aquatic, riparian, and wetland resources, multiple scales must be evaluated (Frissell et al. 1986; Bourgeron et al. 2001b; Jensen et al. 2001). The ARWA protocol presents an interesting challenge for developing appropriate scales of analysis because these systems are influenced by terrestrial processes such as fire and wind but also by processes that occur upstream in the watershed (e.g., erosion) (Jensen et al. 2001; Wohl 2001).

The ARWA protocol utilizes a watershed-based approach for characterizing aquatic, riparian, and wetland ecosystems. Ecosystem boundaries are based on the *National Hierarchical Framework of Aquatic Ecological Unit* (Maxwell et al. 1995) and the *National Watershed Boundary Dataset's* (WBD's) Federal Standards for Delineation of Hydrologic Unit Boundaries (FGDC 2002).

The aquatic ecological unit hierarchy delineates aquatic ecosystems into seven hierarchical categories (subzones, regions, subregions, basins, subbasins, watersheds, and subwatersheds), based on a combination of geoclimatic process properties, unique species and endemism, species group-physiography relationships, and intra-species genetics (Maxwell et al. 1995). These scales have been widely used to characterize aquatic ecosystems (USDA SAMAB 1996; Quigley et al. 1997; Abell et al. 2000) and have been shown to have direct correlation for determining recovery criteria for rare fish that have evolved in river systems in the Rocky Mountain Region (Behnke 1992; Young 1995; Rieman et al. 2000).

The National Watershed Boundary Dataset (WBD) consists of hydrologic unit boundaries defining the area extent of surface water drainage to a nested collection of "pour points" defined *a priori* in the landscape. The WBD hydrologic unit boundaries (HUBs) include six levels (each coded as two digits in a sequential code from largest area to smallest area). The HUBs are a refinement of the "8-digit level 4" hydrologic unit code maps developed by the U.S. Geological Survey (Seaber et al. 1987) in the 1970s, and include

"10-digit level 5" watersheds and "12-digit level 6" subwatersheds. By definition, 10 to 12 watersheds are typically nested within a level 4 HUB and range in size from 40,000 to 250,000 acres. Each watershed typically contains 10 to 12 sub-watersheds ranging in size from 10,000 to 40,000 acres, with some as small as 3,000 acres. Delineation methodology for WBD watershed and sub-watershed HUBs follow procedures used by Maxwell et al. (1995) in delineating watershed and sub-watershed aquatic ecological units (FGDC 2002).

Assessment Protocol Scales

Scale assessments for aquatic, riparian, and wetland resources should be conducted at four spatial scales (Fig. 2.2). Using this multiple scale assessment approach, the most intensive analysis and description will occur at the levels that we have characterized as landscape and management levels. Reach/site analysis is impractical with this type of assessment because of the cost associated with intensive field inventory analysis. However, analysis at other scales could focus efforts at the site specific or reach/site scale to address specific questions identified through the multiple scale assessment.

A Hierarchy of Factors that Influence Species Assemblages

The factors that influence species assemblages can be represented as a hierarchy of natural processes and anthropogenic alterations (Fig. 2.3). At the largest assessment scale or the basin level, the species pool is filtered by natural processes such as glaciation, mountain uplifts, and zoogeographic barriers to produce the landscape level (4^{th} level HUB) species pool.

Anthropogenic factors that affect the landscape species pool include exotic species (Rahel 2000) or creation of transbasin water diversions that provide routes for species invasions (Mills et al. 1994). From this landscape level pool, the distribution of individual species at the management scale or 6^{th} level HUB is often determined by large-scale habitat gradients related to climate (e.g., temperature and precipitation regimes), and landforms and surficial geology that determine the general types of aquatic habitats present in the region. Anthropogenic alterations important at this scale include reservoir construction, the creation of migration barriers, and fish stocking. At the reach/site scale, local habitat factors interact with biotic processes such as competition, predation, or disease to determine species abundances (Tonn et al. 1990). For example, important anthropogenic alterations operating at this scale include habitat degradation from livestock overgrazing, water quality impairment from sewage outfalls, and habitat improvement due to the addition of fish cover structures.

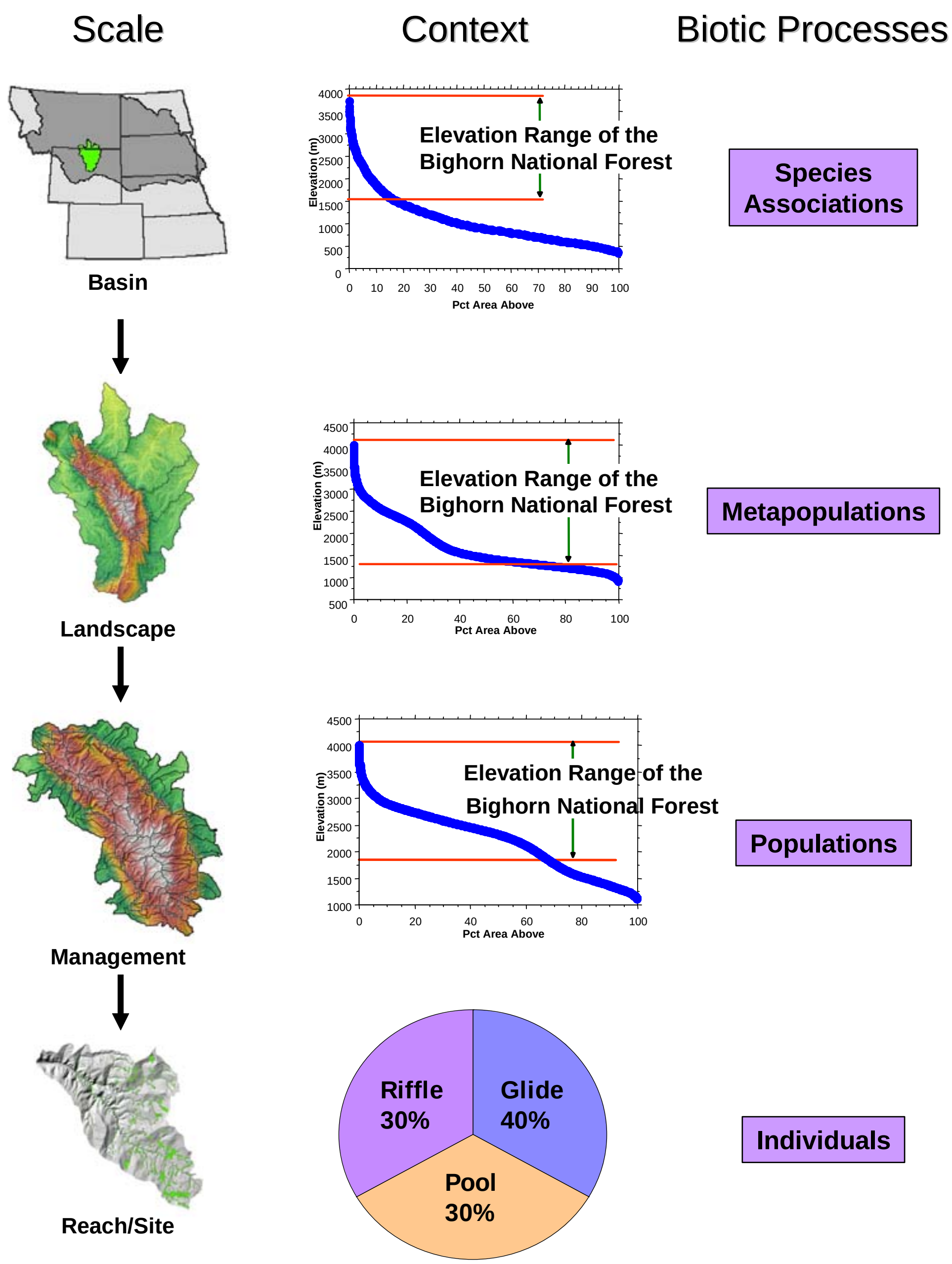


Figure 2.2. Scales, context and biotic processes for addressing aquatic, riparian, and wetland resources.

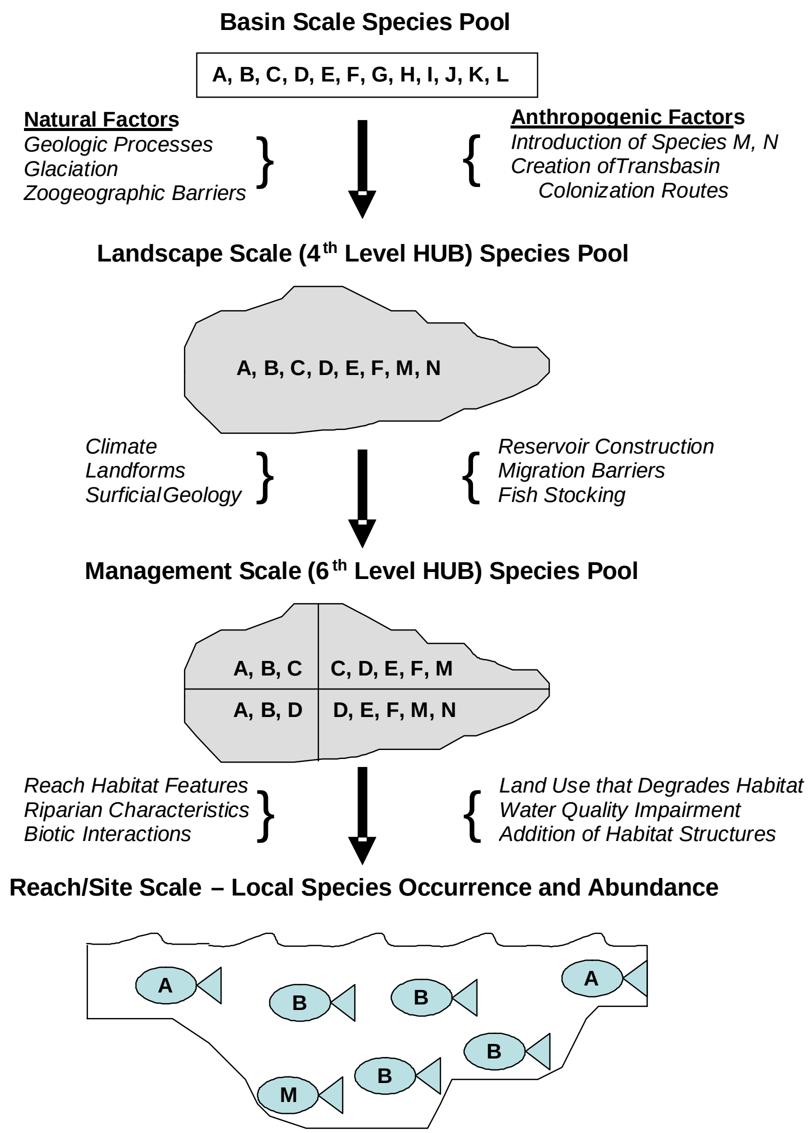


Figure 2.3. A hierarchy of natural and anthropogenic factors determines local species abundances. The basin scale species pool (species A through L) is reduced through natural processes that act as filters to prevent some species from occurring in the landscape scale species pool. At the management scale, the distribution of species is governed by climate, landform, and geology. At the reach/site scale, local habitat conditions and biotic interactions influence species abundances. Anthropogenic factors modify natural processes at each level of the hierarchy. Examples include enhancing the landscape species pool through introductions (species M and N), modifying species distributions by reservoir construction, and altering local abundances by habitat degradation.

Basin Scale represents the broadest unit of analysis and the results of major geologic and biogeographical processes. This scale is characterized by aquatic ecoregions, which typically comprise part or all of a major river basin including large tributary systems (see Fig. 1.2) and the associated riparian areas and wetlands in those basins. Examples of river basins in Region 2 include:

(1) Upper Missouri (Bighorn, Tongue, and Powder Rivers);
(2) Middle Missouri (North and South Platte Rivers);
(3) Southern Great Plains (Arkansas River);
(4) Upper Rio Grande (Rio Grande River); and
(5) Colorado River (Colorado River, San Juan, Gunnison, White, and Yampa Rivers).

The basin scale represents the historic, evolutionary limits of organisms that are restricted to aquatic environments within these systems. For example, the Forests in Region 2 include the headwaters of several river basins. In addition, four sub-species of inland cutthroat trout (*Oncorhynchus clarkii*) inhabit specific basins, e.g., the Yellowstone cutthroat in the Upper Missouri drainage, the Greenback cutthroat in the Middle Missouri and Southern Plains drainages, the Rio Grande cutthroat in the Rio Grande drainage and the Colorado River cutthroat in the Upper Colorado drainage. Interestingly, these cutthroat subspecies originated from the coastal cutthroat form and represent the evolutionary divergence that occurred as a result of isolation during past glacial periods.

Many warm water fishes are restricted to river basins in the region. Indeed, similar species such as the northern redbelly dace (*Phoxinus eos*) found in the Middle Missouri drainage and the southern redbelly dace (*Phoxinus erythrogaster*), found in the Southern Plains drainage, are separated by basin divides that are less than 1 mile apart in some areas. Entire fish assemblages appear to exhibit species replacement between river basins (Baxter and Stone 1995).

Although less understood, other organisms such as mollusks and aquatic macroinvertebrates, are likely to also exhibit speciation within river drainages (Pennak 1978).

The importance of using the basin scale is in part to identify the areas for analysis at smaller scales, which may influence management of a particular native species. For example, a Forest may want to consider habitat conditions and restoration treatments based on the historic range of a species or ecosystem type rather than based on administrative boundaries.

Analysis conducted at the basin scale is limited to narrative descriptions addressing the following:

(1) Landforms and how they developed.
(2) Influence of the last glaciation period.
(3) Evolutionary pathways of fish and other organisms through the influences of glaciation and longitudinal movements in stream systems.
(4) Position of National Forests and Grasslands in the landscape.
(5) Relative amount of National Forest System land in the context of the basin.
(6) Anthropogenic influences both spatially and temporally.

Hypothetical Management Example: There are two National Forests within a given river basin. As in almost all the basins associated with Region 2, there is an endemic cutthroat in this basin. Analysis at the landscape or management scales that are within this basin reveal that there is only one 6th level Hydrologic Unit Boundary (HUB) associated with both Forests which have the characteristics optimum for native cutthroat trout production. Rather than focusing on areas within both Forests, it would be more effective to focus on the one best HUB. Without this basin level context, lesser productive HUBs could be inadvertently identified.

Landscape Scale encompasses the management unit addressed in Forest planning (Fig. 2.4).

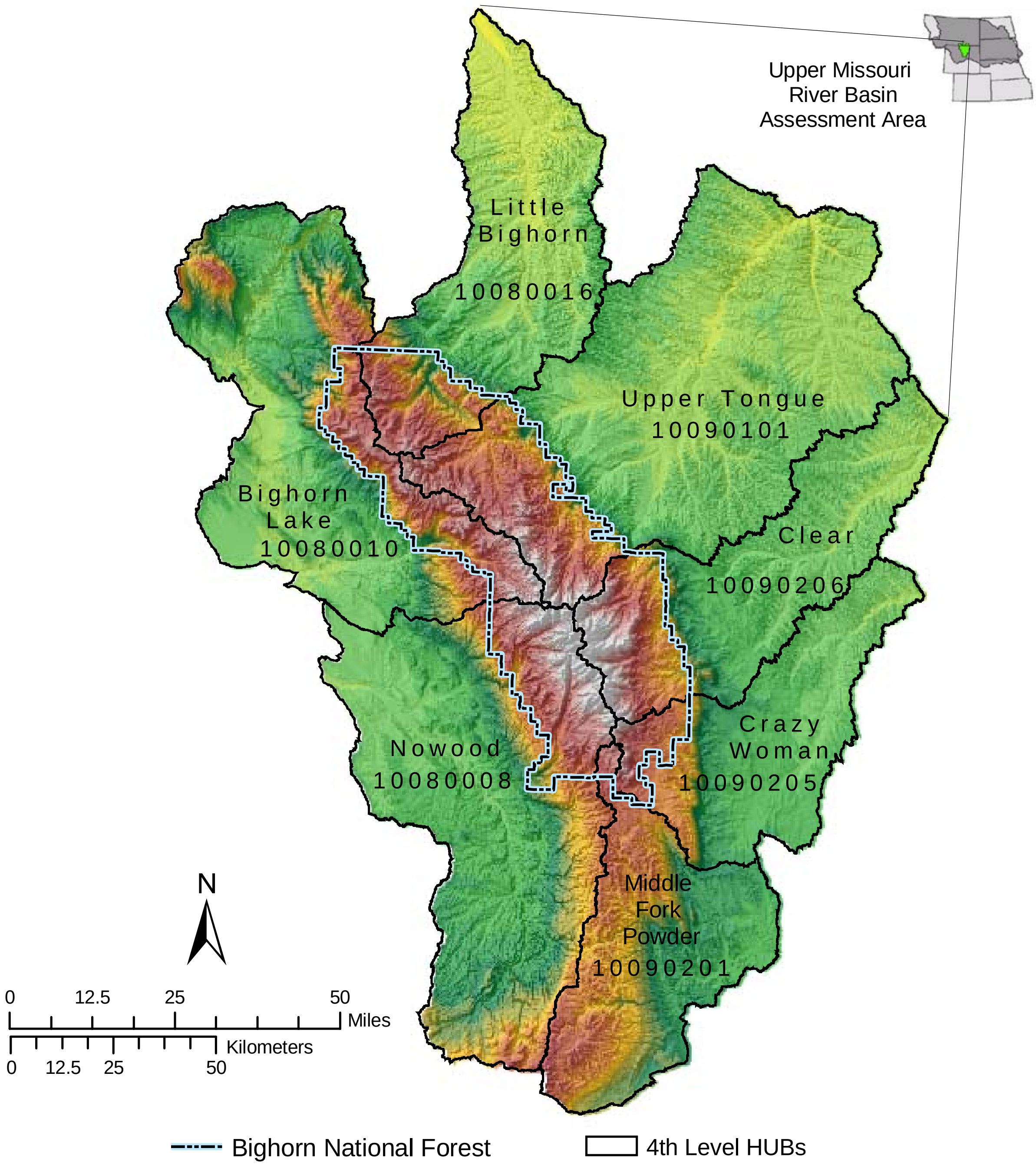


Figure 2.4. Landscape scale of the Bighorn ecosystem showing 4th level HUBs or watersheds.

At the landscape scale we include all 4th level HUBs that intersect the particular Forest or Grassland we are addressing. The outside boundary of these units is identified as the limit of our landscape scale. Individual 4th level HUBs will be compared to others and will consider the magnitude of anthropogenic impacts that exist within their boundaries.

Some analyses will be limited to Forest Service jurisdictional lands whereas other analyses will occur within the entire watershed depending on management needs and available information. Factors will be identified that have utility at this analysis level, and these factors will determine what measurements are to be used and the level of specificity required to determine areas of similar ecological form and function.

Hypothetical Management Example: Analysis at the landscape scale reveals that the ecological characteristics identified at this scale are considerably different within the National Forest boundary than outside. The area within the National Forest boundary is also considerably less than outside. These results would indicate that the ecological conditions within the National Forest boundary related to aquatic, riparian, and wetland resources may be relatively rare in the context of the bigger landscape and should be considered appropriately in management contexts.

<u>Management Scale</u> incorporates the analysis conducted in the landscape scale and further "refines" the process within the management scale boundary (Figs. 2.5 and 2.6). This spatial level of analysis corresponds to a 6th level HUB that intersects the appropriate administrative boundary. Analysis at this scale is very important for the Forest Service for several reasons:

(1) We can utilize the information from the landscape analysis scale to understand form and function similarities at a finer scale. The 6th level HUB is used because it is generally perceived as a manageable spatial unit in the Forest Service, important for measuring effective population size for native fish (Rieman et al. 2000), and is based on watershed delineations used by other state and federal agencies. Information will be incorporated from the landscape scale as well as additional drivers. This will enable statistical analysis of each watershed in comparison with others to determine which watersheds "should" function similarly. By knowing this, at the next finer scale we can compare across watersheds to understand each watershed's "relative" condition.

(2) This is the appropriate scale to address management influences (e.g., anthropogenic disturbances) for a landscape assessment. These watersheds are fairly similar in size, making measurements such as road density, grazing density, and other anthropogenic influences more comparable. By addressing these issues at a 6th level HUB; watersheds that are most in need of restoration can be identified.

(3) This is also the appropriate scale to address "high value" systems. Although wetlands and riparian systems may be protected on a site basis, we may find that some watersheds have an inordinately large number of fens or other wetland types. These may be set-aside as protection areas. In addition, if we look at the appropriate factors in the assessment, we can identify watersheds that should be a high priority for recovery of native species, such as cutthroat trout. By going through this analysis we may find that some watersheds have the attributes that will increase the odds of recovery relative to others (e.g., watersheds without a high number of diversions).

(4) This is also an appropriate scale to assess risk from a management context, e.g., which watersheds are at a higher risk from particular anthropogenic disturbances based on the ecological driver analysis.

Hypothetical Management Example: Analysis of 55 6th level HUBs associated with a particular National Grasslands reveals that only six have characteristics, which are favorable for abundant wetlands. Existing wetland inventories reveal that indeed, approximately 45% of all wetlands at this

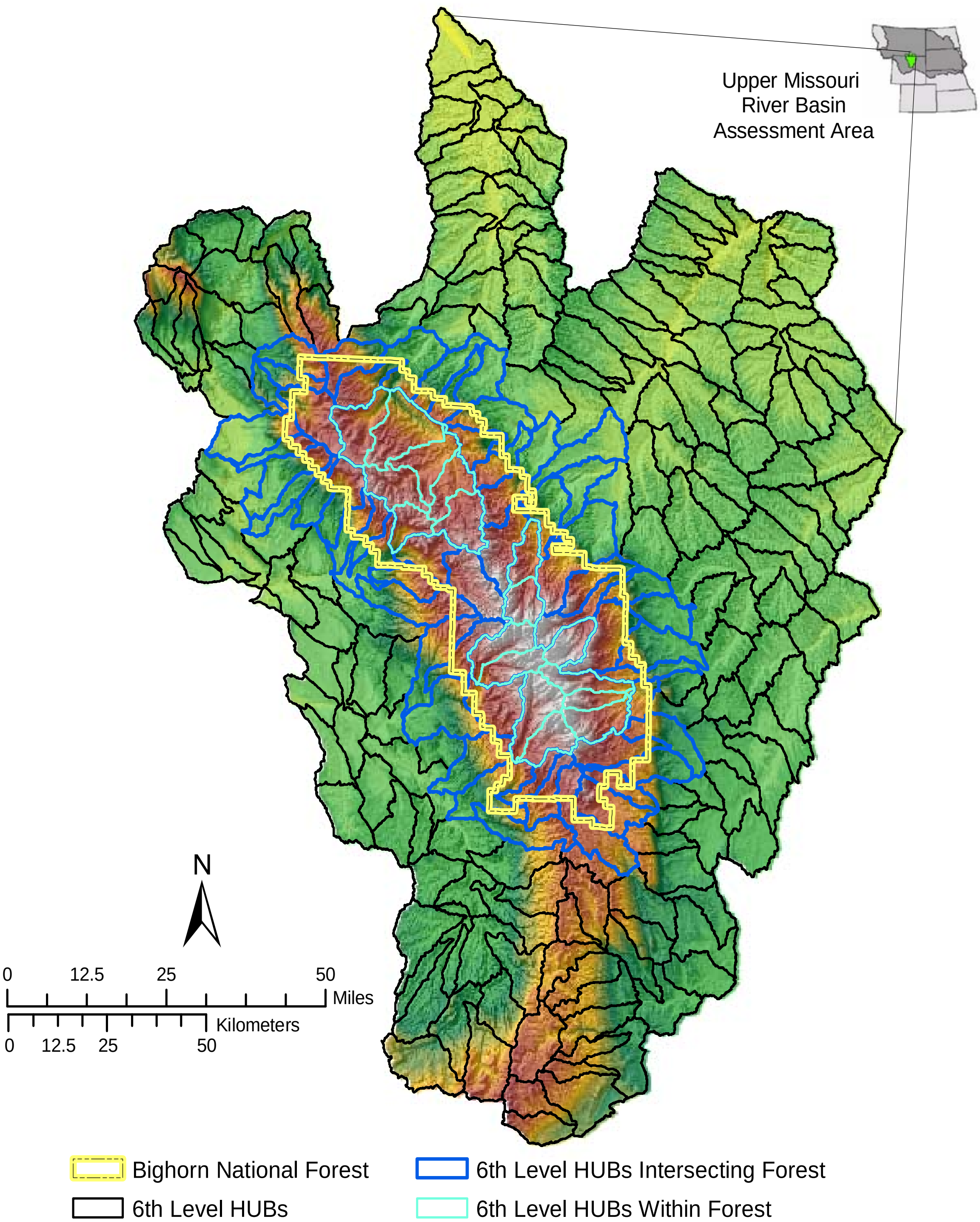


Figure 2.5. Management scale of the Bighorn ecosystem showing 6th level HUBs.

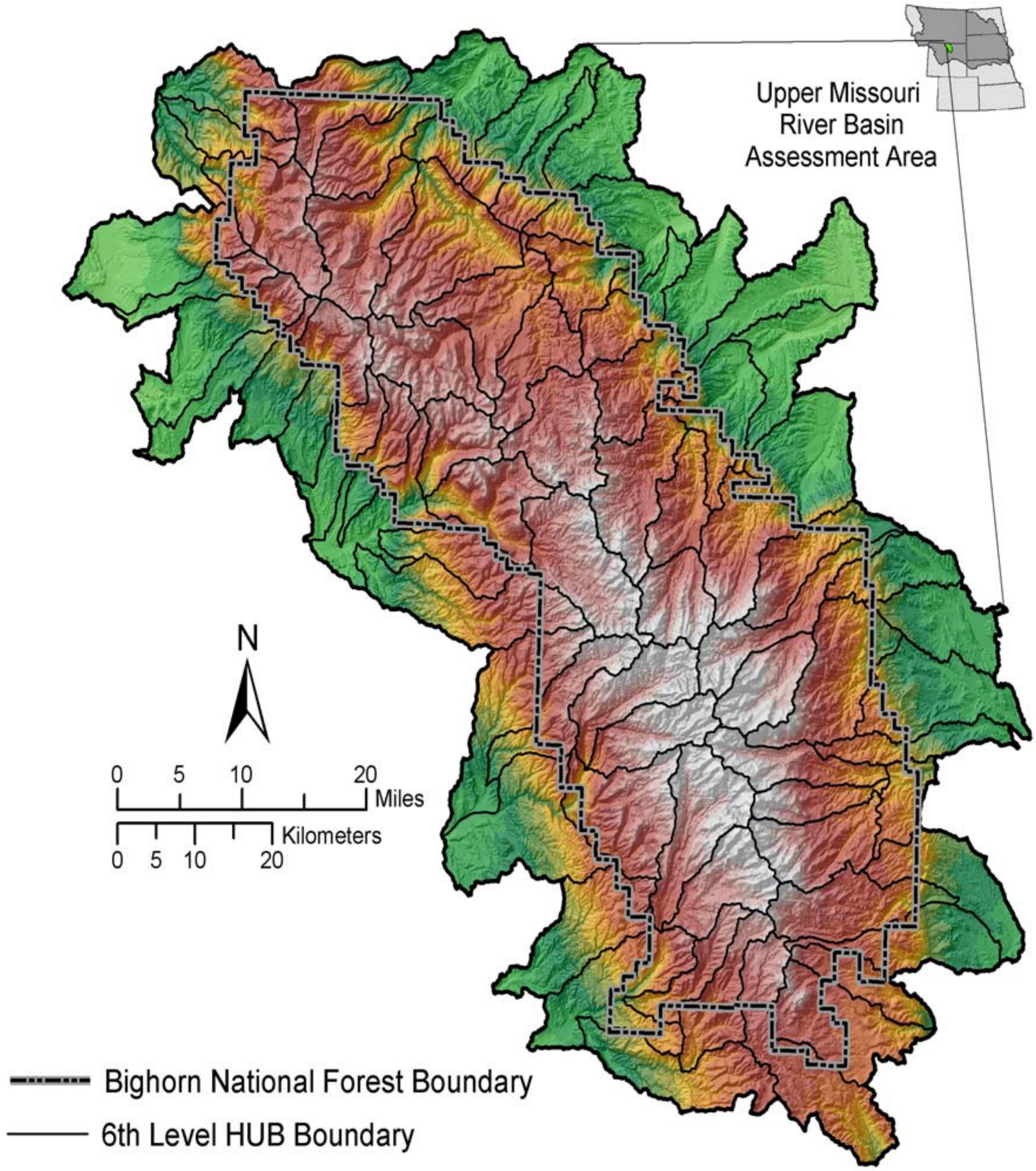


Figure 2.6. Management scale of the Bighorn ecosystem showing 6th level HUBs that intersect the Forest Service boundary.

scale are located in these HUBs. Information can now be incorporated in the Forest Plan to ensure that these areas are considered appropriately in management direction.

Reach/Site Scale analysis can identify important and measurable fine-scale attributes in watersheds, including specific riparian and wetland forms, channel types, and stream habitat units (Fig 2.7).

Although reach/site measurements will not be gathered as part of the broad scale assessment, it is important that features influencing aquatic, riparian, and wetland habitats at this scale be identified. Whether these habitat types should be expected on the landscape and how they may be significantly impacted by land use should be assessed. The protocol provides guidance to Forest personnel regarding the important parameters that need to be identified and measured at the reach/site scale to make planning consistent with the context established by the broad scale assessment. An example of the reach/site scale is provided in Figure 2.7.

Hypothetical Management Example: Analysis at the management scale reveals that there were three 6th level HUBs, which contain characteristics conducive to abundant riparian vegetation communities. Two of these HUBs have had historic management practices occurring in them that have limited riparian vegetation development. The other HUB is located in an isolated part of the National Forest and has received very limited management. Reach and site level measurements of key characteristics within this HUB can then be used as reference levels for restoration goals in the two other impacted HUBs.

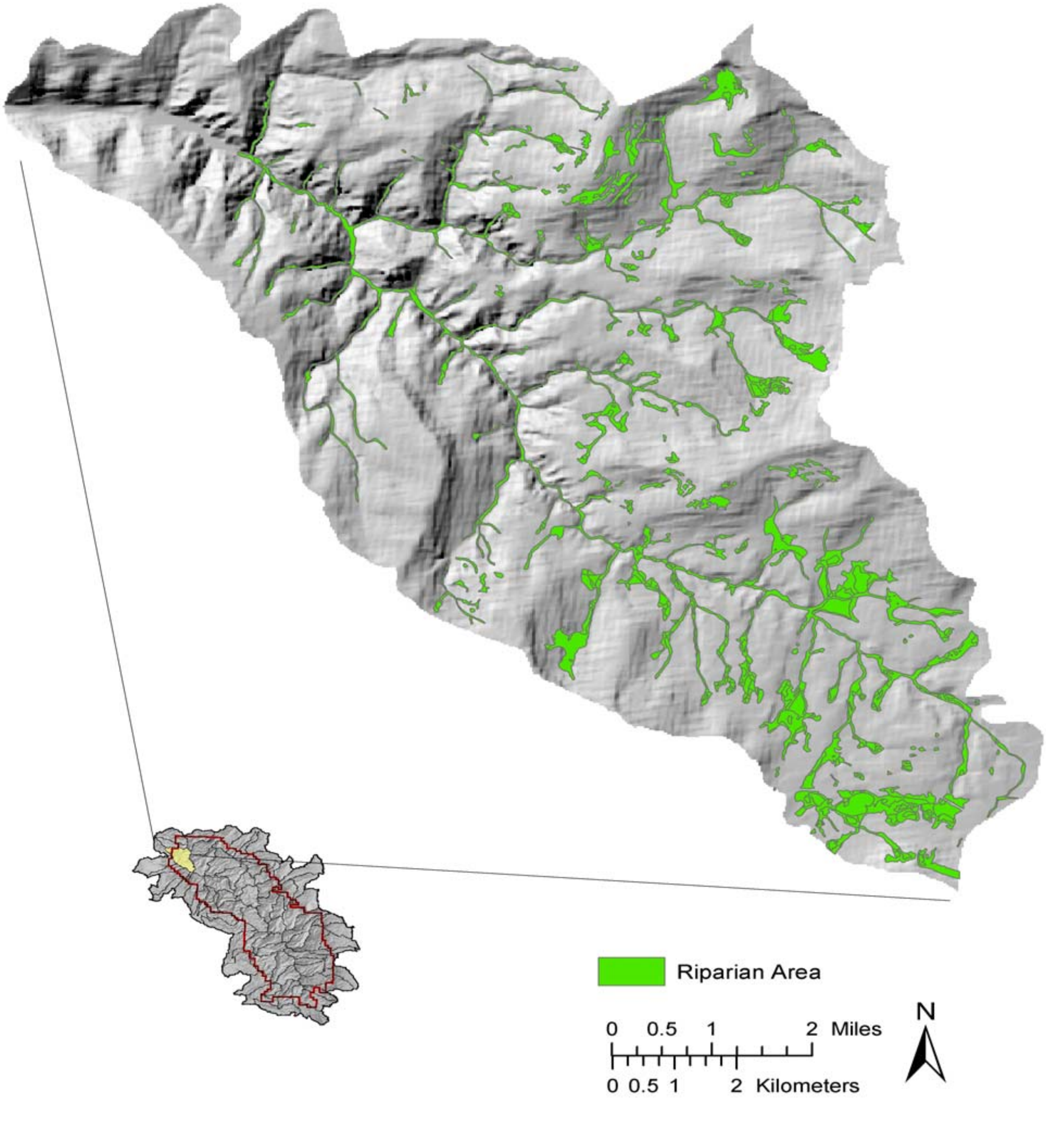


Figure 2.7. Reach/site scale of a 6th level HUB in the Bighorn ecosystem**.**

CHAPTER 3
ECOLOGICAL CHARACTERISTICS OF AQUATIC, RIPARIAN, AND WETLAND ECOSYSTEMS

Introduction

Attempting to address all the components of aquatic, riparian, and wetland resources in a multiple scale assessment is beyond the scope of this effort. Rather, we have chosen to focus our efforts on specific aspects that we feel are critical to the form and function of ecosystems in the Rocky Mountains and are important from a management context within the U.S. Forest Service. The following narrative represents the current understanding of these ecosystems from a physical, biological, and chemical standpoint. This chapter defines the physical characteristics, riparian and wetland resources, and the aquatic invertebrate and fisheries resources concepts, which are important to understand for the subsequent application chapters.

Physical Characteristics

HUB Scales, Spatial Information, and Ecoregional Connections

The organizing framework for assessing the physical characteristics of aquatic, riparian, and wetland ecosystems is centered on three flow charts (Fig. 3.1a-c). The first set of physical characteristics is designed to be regional in scope, and can be readily applied to first through fourth level HUBs or at the landscape scale. The common aspect of applying this first spatial level to varying scales is that the relevant data can be obtained from existing published information such as climate and discharge records, geology and vegetation maps, etc. This scale can be used to delineate elevation bands *within* large drainage basins (e.g., Rio Grande or South Platte) or *across* large drainage basins, depending on the species of interest and whether they are restricted to a single drainage basin.

The second set of physical characteristics is designed to be more local in scope and can be applied to the 4th through 6th level HUBs or at the landscape and management scales. This requires information not necessarily readily obtained from published sources. Data on channel morphology, sediment regime, or groundwater input, for example, will likely be obtained from field investigation data at the reach/site scale.

Depending on the mobility of individual species, units designated at the landscape and management scales that cross drainage divides or that are geographically isolated from one another may or may not have the same species distribution. For example, an elevation-defined band with a snowmelt flow regime may be continuous from the crest of a mountain range down to the base of the mountain front on both sides. Yet different fish species may be present within this band because each side of the mountain range is in a different drainage basin. In general, the categories described at the landscape scale should have similar community types (e.g., cold water vs. warm water fish fauna) even if individual land areas within a category are geographically separated.

Physical Characteristic Criteria

The physical characteristics within Region 2 are a function of (1) latitude, longitude, elevation and aspect, all of which determine climate; and (2) lithology, which controls soils and along with climate controls the hydrologic and sediment regimes.

In mountainous regions, the hydrologic and sediment regimes will vary dramatically as a function of elevation and local relief, as well as drainage basin size. For example, a portion of a Colorado Front Range drainage basin between 12,000 and 10,000 feet elevation is likely to be dominated by a snowmelt flow regime with sediment introduction being dependent on stream size and proximity of channels to hillslopes. In the Great Plains, drainage basin size should be the primary source of variability. For example, both a 10 sq. mi. drainage basin and a 1,000 sq. mi. drainage basin will be dominated by convective rainfall and have similar sediment regimes but the smaller basin will have a much higher frequency of large floods.

For each physical characteristic, controls are defined. Controls are the physical factors, such as climate or lithology, determining the hydrologic and sediment regimes. These factors also constitute the types of information that are needed to determine hydrologic and sediment regimes.

Each physical characteristic also has categories with which this characteristic can be described. For example, for Region 2 the hydrologic regime will be predominantly snowmelt, frontal rain, convective rain, or a rain and snow mixture. Each of these categories implies a different magnitude, frequency, and duration or seasonality of flow.

Controls Associated with Landscape and Management Scales

Form and Function Related to Driver Concept

The three types of ecosystems addressed in this protocol – aquatic, riparian, and wetland ecosystems – can be described in terms of form and function. Form refers to the basic physical appearance of an ecosystem. For rivers, form includes channel sinuosity, width/depth ratio, and grain size. For riparian areas and wetlands, form includes spatial extent, topography, and water levels. Function refers to the physical, chemical, and biological processes that create and maintain form. For example, the grain size of a river could be governed by numerous factors, including: rock type, climate, and topography as these control sediment introduction from adjacent hillslopes; transport of sediment from upstream; discharge regime; and complexity of the channel geometry as this interacts with discharge regime to govern hydraulics and thus sediment transport. All of these factors together govern river function.

The controls listed on the flow charts in Figure 3.1a-c are chosen to include the range of factors that govern form and function in aquatic, riparian, and wetland environments. These controls were simplified to five basic types of drivers for aquatic, riparian, and wetland ecosystems: geology, climate, glaciation, stream gradient, and temperature. Each driver is subdivided as appropriate for a given region. For example, geology in the Bighorn National Forest assessment was divided into calcareous versus non-calcareous rocks and presence or absence of glaciation. These subdivisions were chosen because calcareous rocks influence water chemistry and produce different sediment-size distributions than do non-calcareous rocks. Also, glaciated regions have distinctly different valley morphology than unglaciated regions (Fig 3.2).

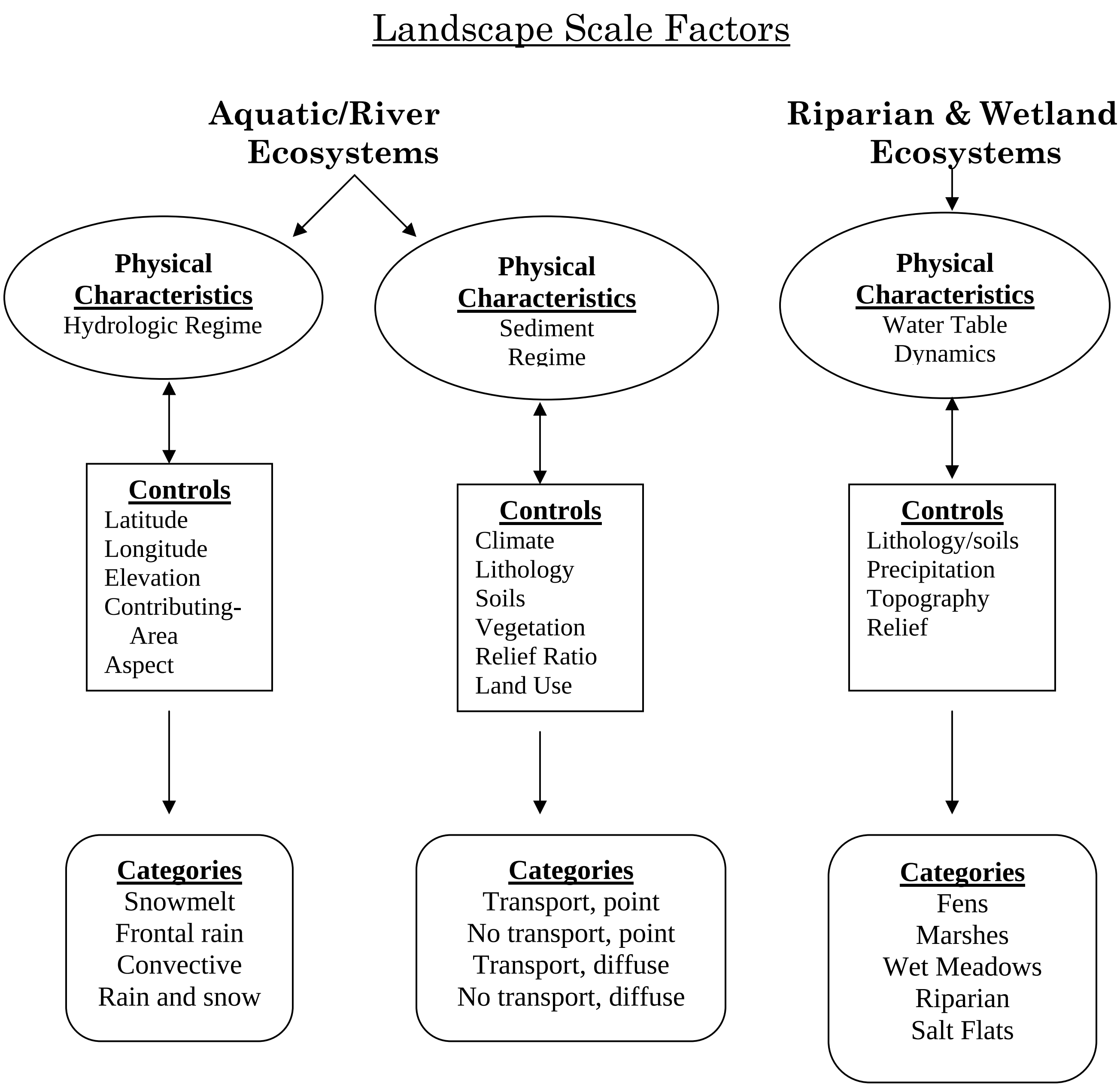


Figure 3.1a. Physical characteristics, controls, and categories for aquatic, riparian, and wetland ecosystems at the landscape scale.

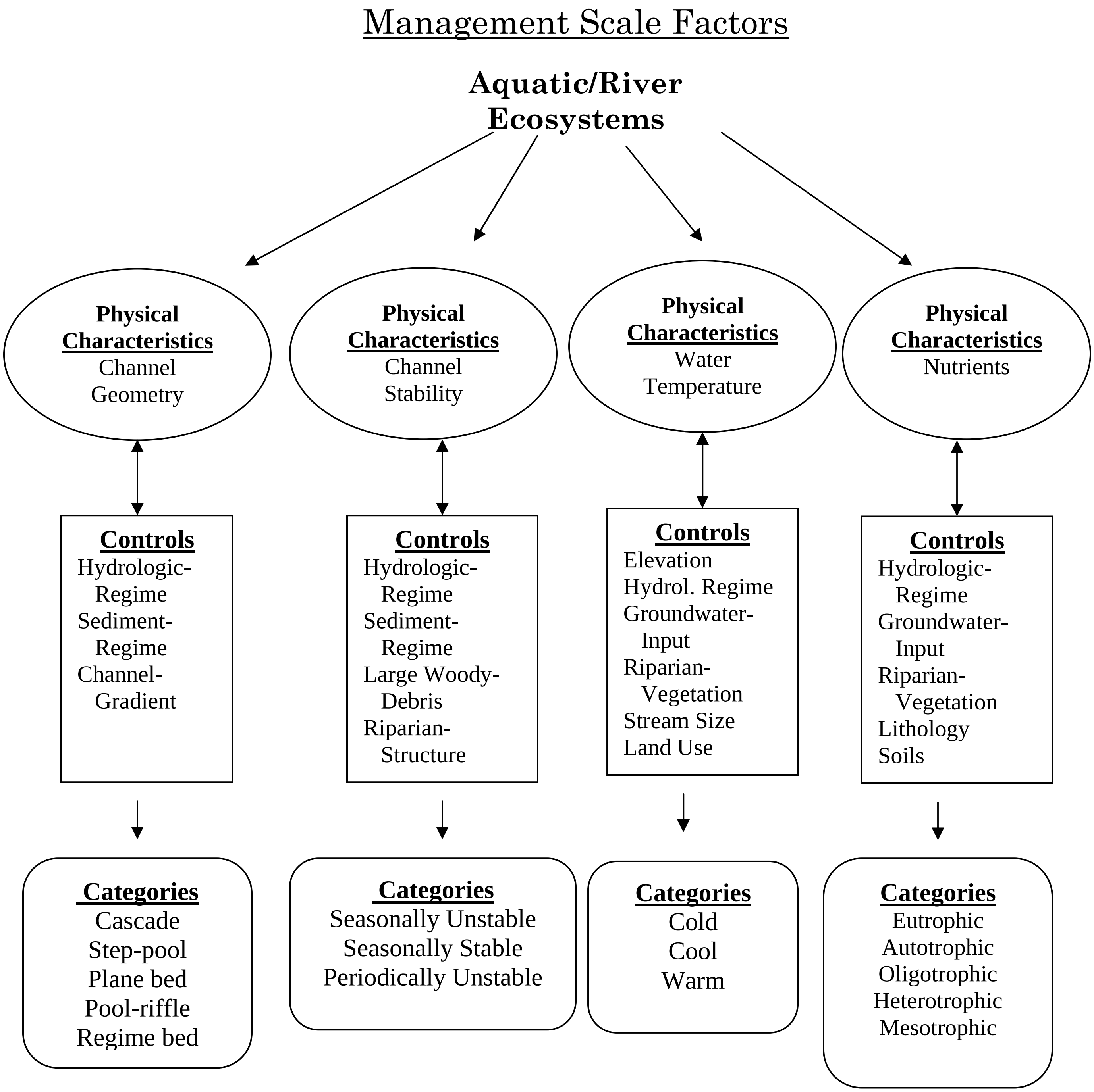


Figure 3.1b. Physical characteristics, controls, and categories for aquatic ecosystems at the management scale.

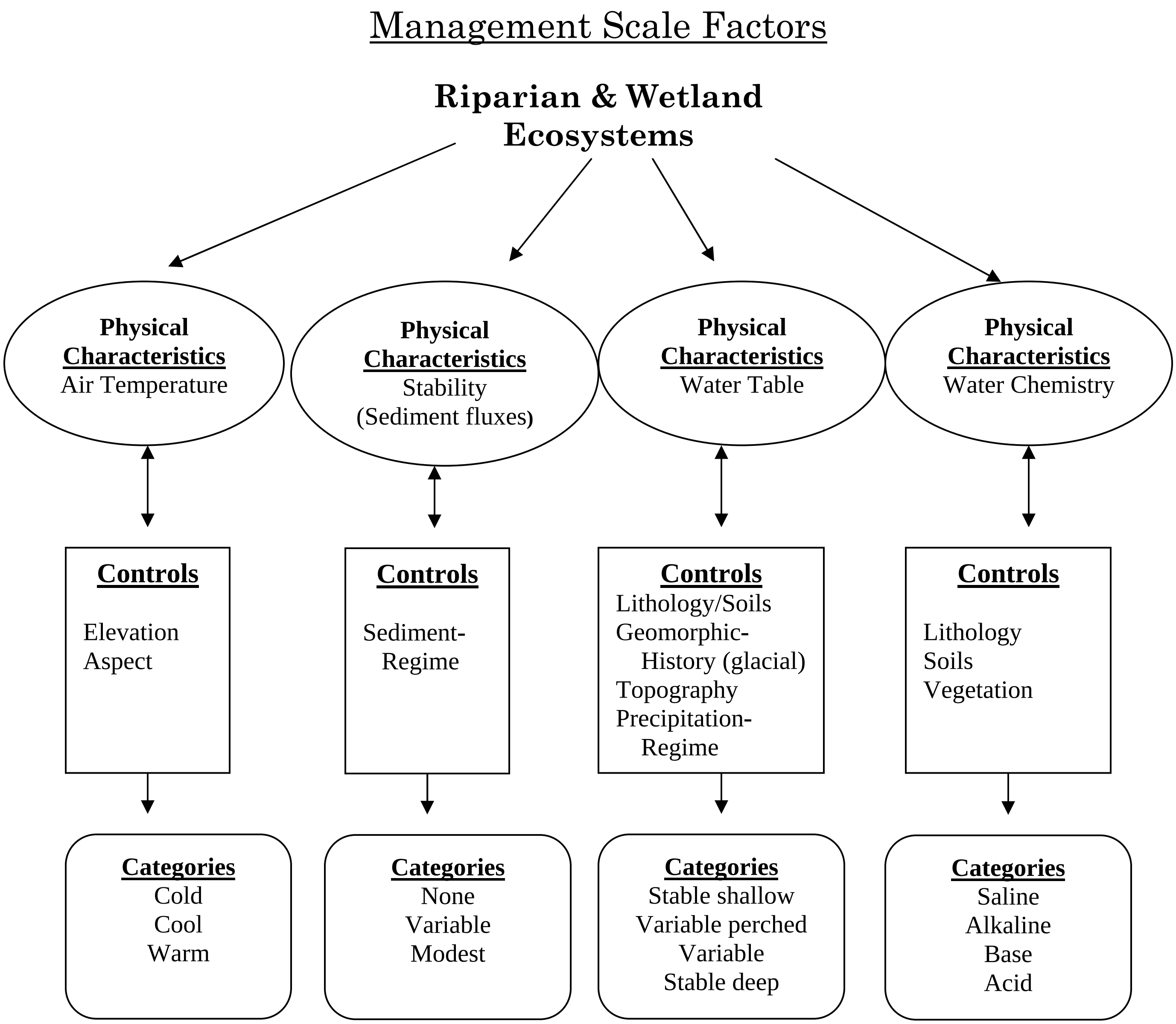


Figure 3.1c. Physical characteristics, controls, and categories for riparian and wetland ecosystems at the management scale.

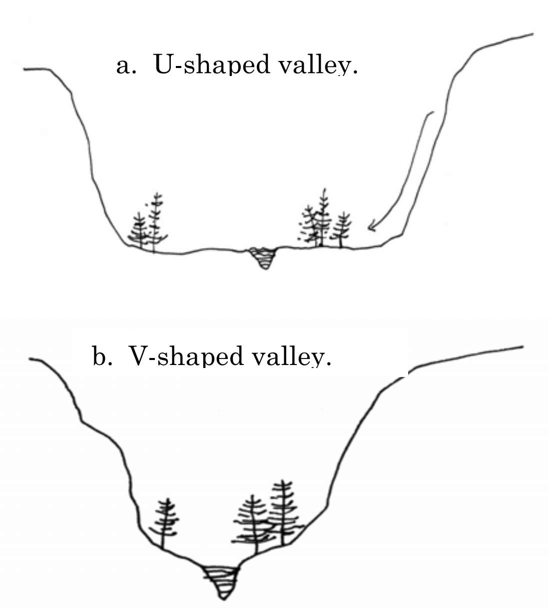


Figure 3.2. Drawings of U- and V- shaped valleys. (Drawings courtesy of Judy Dersch, 2002).

For a National Grassland unit that was not glaciated a more appropriate subdivision of geology with respect to rivers might be bedrock versus alluvial. Individual driver categories can be combined so that all the most important physical controls are listed for a given aquatic, riparian, or wetland environment.

Landscape Scale Factors

Aquatic Ecosystems

For rivers, hydrologic and sediment regimes are the two most important factors at a coarse spatial scale such as a river basin scale.

Hydrologic Regime is determined by five controls that are related to precipitation characteristics. The five controls are: latitude, longitude, elevation, contributing area, and aspect.

Latitude and longitude will determine air-mass distribution and circulation, and hence precipitation type (Bryson and Hare 1974; Collins 1990), timing, and volume (Hayden 1988; Jarrett 1993).

Elevation and contributing area also govern precipitation characteristics (Wohl 2000). Two sites at the same elevation might have different hydrologic regimes because of different contributing areas. For example, one site might have a small contributing area at higher elevations and have only streamflow generated by rainfall. Whereas, a different site, at the same elevation, might have substantial snowmelt from upslope contributing areas as well as rainfall at the site.

Aspect might also govern precipitation regime (Barry and Chorley 1987). For example, the western slope of the Colorado Rockies is wetter than the eastern slope.

These five controls combine to produce the four basic hydrologic regimes. The four hydrologic regimes are those dominated by:

(1) Snowmelt runoff;
(2) Runoff from frontal rain systems (e.g., widespread lower intensity rains);
(3) Runoff from spatially isolated and intense convective rainfall; and
(4) Rain and snow precipitation.

Sediment Regime is a function of six controls related to regolith thickness and slope stability. The controls are climate, lithology, soils, vegetation, relief ratio, and land use.

Climate and lithology, or rock type, will determine the type of sediments produced by bedrock weathering and the rate at which these sediments are produced (Ritter et al. 1995). Climate will also interact with soils to determine the downslope pathways of water (surface vs. subsurface) (Selby 1982).

Soils are listed separately from lithology because the same lithology exposed to different climates and weathering regimes, can produce very different soils.

Vegetation exerts a control on weathering rate and also acts to stabilize weathered materials on hillslopes.

Relief ratio is the difference between the highest and lowest elevations divided by the horizontal distance, for a study area (Ritter et al. 1995). Relief ratio is thus a measure of landscape and hillslope steepness, which partly governs slope stability.

Land use may act to destabilize hillslopes (e.g., timber harvest, road building, etc.) to the point that this control overrides any of the other five controls (Wohl 2000).

The six controls together determine the amount of weathered, unconsolidated material on hillslopes or regolith thickness and the stability of those slopes.

Sediment regimes have been divided into four categories (Figs. 3.1a, Photo 3.1 and 3.2.):

(1) *Transport, point* refers to hillslopes with point sources of sediment input to the stream (e.g., mass movements such as debris flows or landslides) and sediment of a size distribution capable of being transported by the receiving stream;
(2) *No transport, point* refers to situations where the stream is not capable of transporting the sediment delivered by point sources;
(3) *Transport, diffuse* refers to hillslopes with continuous sediment introduction to streams via soil creep; and
(4) *No transport, diffuse* refers to hillslopes where the continuously introduced sediment cannot be transported by the stream, as in a canyon with talus slopes and rockfall.

Riparian and Wetland Ecosystems

The interaction between surface and groundwater is defined as water table dynamics and is important in riparian and wetland ecosystems at the landscape scale.

Water table dynamics are a function of four controls that govern interactions between surface and groundwater at the basin scale. *Lithology* and *precipitation* will govern infiltration potential and water storage. *Topography* and *relief* will determine rates of groundwater movement, along with porosity and permeability. Topography and relief will also control groundwater recharge potential.

Photo 3.1. Example and drawing of a transport diffuse hillslope sediment source. This photograph shows rilling and movement of sand and gravel-sized sediment along the hillslopes, about two months after a forest fire. (Drawing courtesy of Judy Dersch, 2002).

Photo 3.2. An example and drawing of a transport, point source of sediment from a hillslope. It is a view of a debris-flow channel and fan on a hillslope. (Drawing courtesy of Judy Dersch, 2002)

Five categories (Fig 3.1a) are created by different water table dynamics and are described below and in more detail under the Wetland and Riparian Resources section of this chapter:

(1) Fens - most water is from groundwater and there is little sediment deposition or erosion;
(2) Marshes - pulsed hydrologic regime with periods of high and low water. There may be considerable sediment fluxes into these systems;
(3) Wet Meadows - supported primarily by groundwater. Water tables are near the surface in early summer and deeper through the rest of the year and may be dry for much of the time;
(4) Riparian - wetlands on stream sides and floodplains with seasonal pulses of water and sediment; and
(5) Salt Flats – terminal sump basins that dry out each year with high soil salt concentrations.

<u>Management Scale Factors</u>

At the management scale, rivers may be categorized in terms of channel geometry, channel stability, water temperature, and nutrients. Riparian and wetland ecosystems may be described in terms of air temperature, stability with respect to sediment fluxes, water table conditions, and water chemistry.

Aquatic Ecosystems

For rivers, the hydrologic and sediment regimes as described in the landscape scale section above will be the controls for most of the river characteristics at the landscape scale.

For the channel geometry (Figs. 3.1b and Photos 3.3 through 3.6), the resulting categories are from a system developed by Montgomery and Buffington (1997), that classifies channel geometry on the basis of the dominant bedforms:

(1) Cascade - no organized bedforms, steep gradients and coarse clasts;
(2) Step-pool - steep gradients, coarse clasts, channel-spanning steps of clasts, logs or bedrock, and intervening pools;
(3) Plane bed - uniform, low-relief channel bed with intermediate gradient;
(4) Pool-riffle - intermediate gradient, downstream alternations between pools and riffles; and
(5) Regime bed - sandy bed on which bedforms change in a matter of minutes to hours between ripples, dunes and antidunes in response to changes in hydraulics.

For channel stability, categories are chosen with respect to bed sediment movement as it affects macroinvertebrates. The categories are:

(1) Seasonally unstable – median grain size of bed sediment (D_{50}) is mobilized annually during the season of high flow;
(2) Seasonally stable - D_{50} bed sediment is not mobilized during annual high flows; and
(3) Periodically unstable - D_{50} bed sediment is mobilized infrequently during very large floods.

These categories are designed to reflect coarse-grained, snowmelt dominated channels (seasonally stable); finer-grained channels with snowmelt or rainfall hydrologic regimes (seasonally unstable); and coarse-grained channels with convective rainfall hydrologic regimes (ephemeral or at least with highly variable discharge annually and inter-annually).

Many of the characteristics described above, including channel geometry, channel stability, and sediment regime change progressively with channel gradient (Fig. 3.3), hence the choice of gradient as one of the four basic drivers for streams.

For water temperature, the categories cold, cool, and warm water were borrowed from stream fauna classifications.

For nutrients, the categories of eutrophic, oligotrophic, and mesotrophic or alternatively, autotrophic and heterotrophic, were borrowed from biological classifications.

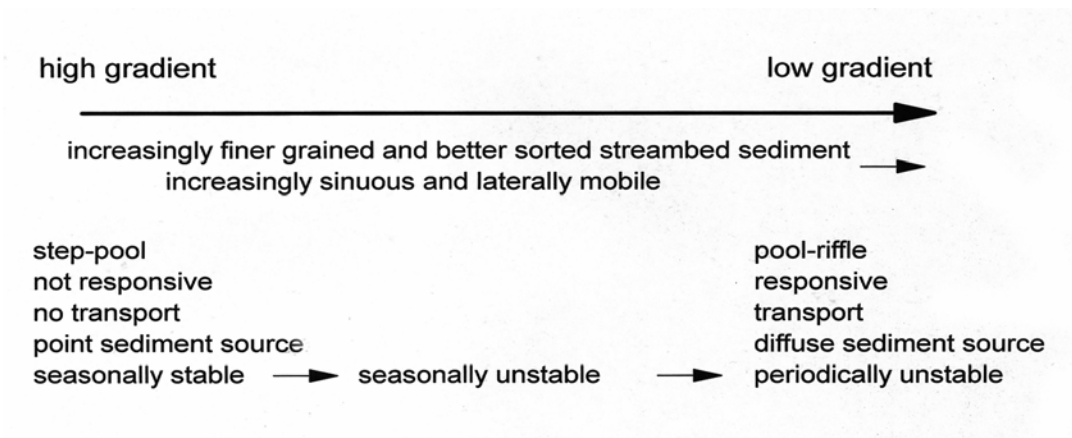


Figure 3.3. Schematic representation of channel characteristics and sediment inputs in relation to downstream channel gradients.

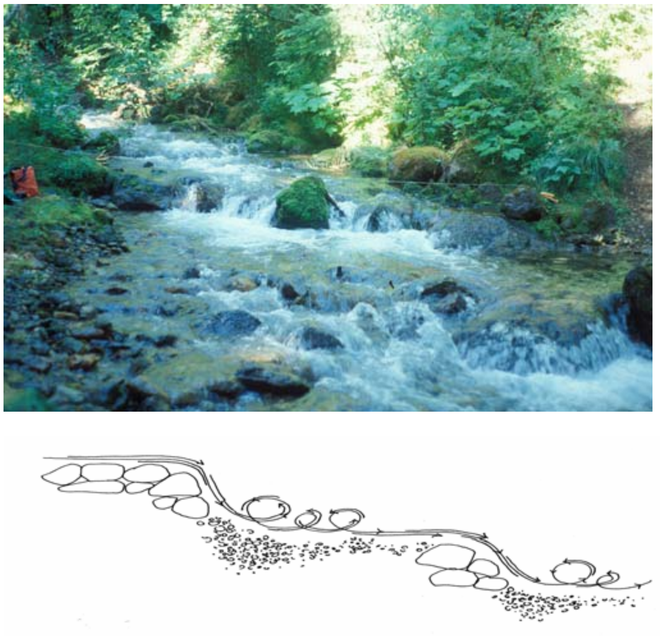


Photo 3.3. Example and drawing of a step-pool channel morphology. In this channel type, large clasts are organized into vertical downsteps spanning the channel perpendicular to flow. These steps alternate downstream with plunge pools at the base of each step. (Drawing courtesy of Judy Dersch 2002).

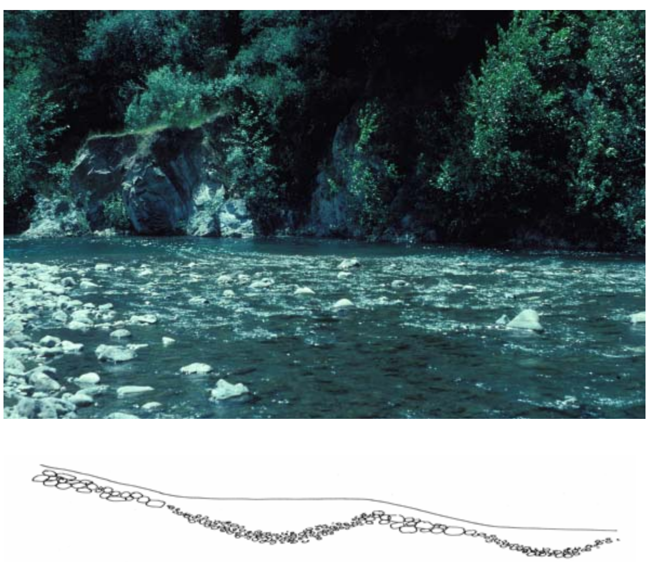


Photo 3.4. Example and drawing of a pool-riffle channel with alternating topographic lows (pools) and highs (riffles) along the streambed. View is looking downstream along a riffle to a pool (flat water surface). (Drawing courtesy of Judy Dersch 2002).

Photo 3.5. Example of a plane-bed channel. In this channel type, the channel bed does not have regularly repeating highs and lows (such as steps and pools or pools and riffles) in a downstream direction.

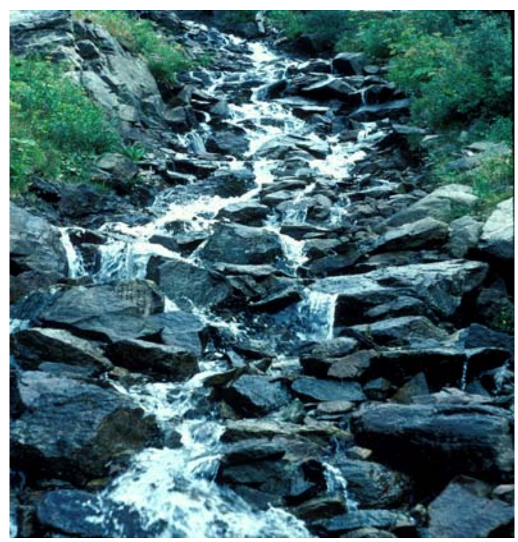


Photo 3.6. Example of cascade channel morphology. In this channel type, the streamflow is not capable of transporting the coarse sediment present in the channel, so the water flows among unorganized large clasts. Clasts tend to be angular.

Riparian and Wetland Ecosystems

For wetlands, four additional characteristics have been chosen (Fig. 3.1c). *Air temperature* will affect the flora that can occur at any site, which can affect site functioning. Cold, cool, and warm are provisional air temperature categories.

Stability relates to sediment fluxes. The stability category *none* describes peatlands, which have essentially no mineral sediment flux. *Variable* refers to riparian areas in which sediment flux can vary from substantial to minimal, depending on stream type. *Modest* refers to marshes and meadows, which have low to modest sediment fluxes. These systems are partly groundwater-fed and also have surface inputs but generally not of the type that can lead to sediment accumulation.

Controls that influence the water table include the following:

(1) *Lithology and soils* will influence porosity and permeability and the ability of water to move through the subsurface.
(2) *Geomorphic history*, specifically the history of glaciation and the presence or absence of glacial deposits, influences shallow subsurface porosity and permeability.
(3) *Topography* will also influence the rate of subsurface water movement.
(4) *Precipitation regime* will influence infiltration vs. surface runoff and therefore the water available in the subsurface.

The category *stable shallow* refers to peatlands, which have relatively stable water tables, generally within 20 cm of the soil surface. A *variable perched* water table refers to marshes, which will be flooded for periods of time during most years but may also remain dry for long periods of time. Many marshes are perched, e.g., not connected to regional groundwater. A *variable* category refers to riparian sites, which can vary from small to substantial water table fluctuations that in Region 2 can be on the order of 20-40 cm to 3-4 m. *Stable deep* refers to meadows, which have water tables that are deeper than peatlands, typically from the surface to 60 cm but do not have permanently high water tables.

For water chemistry three controls have been chosen: lithology, soils, and vegetation (Fig. 3.1c).

Lithology exerts an important control on water chemistry in terms of weathering products. For example, limestone vs. granite weathering produces large differences in pH and calcium concentration, which creates an important gradient in peatlands from areas richly supplied with ions to those poorly supplied.

Soils influence the microbial community, nutrient cycling, permeability, porosity, the rate of water movement and interaction with soil matrix and this also controls water chemistry.

The presence of different types of *vegetation* and the associated nutrient uptake and recycling will provide another control on water chemistry.

Summary of Scale Factors

Many of the characteristics, controls, and categories listed in Figure 3.1a-c are closely interrelated and some of the distinctions that are defined are rather arbitrary. There will also be inevitable overlap among the categories of any classification. For example, the hydrologic regime of a river along the Front Range of the Rocky Mountains, such as the Poudre River, may be snowmelt in the upper reaches and snowmelt with superimposed convective rainfall in the middle to lower reaches (below approximately 7,600 ft in elevation) (Jarrett 1993). Some of these overlaps may be resolved as we continue to refine this system based on biological or ecological criteria. Some of the overlaps may remain and it may be necessary to prioritize which category to choose in case of overlap.

In the example above, the convective rainfall might be the most important part of the lower Poudre River hydrologic regime, because this rainfall causes the channel to fall into the channel stability category of seasonally unstable or periodically unstable, whereas the upper Poudre River would be seasonally stable.

Riparian and Wetland Resources

Almost all of the surface water and a large portion of the shallow groundwater in the Rocky Mountain west and Great Plains flows through wetlands and riparian areas at some point along its course to the ocean (Winter et al. 1998). Ecological processes occur within these wetland and riparian ecosystems that provide critical functions and important goods and services at local, national, and international scales (Mitsch and Gosselink 1993; National Research Council 1995).

Riparian ecosystems occupy floodplains and stream banks providing bank erosion protection, shade streams and provide allochthonous inputs of organic matter and nutrients, and may regulate surface and groundwater temperature and water flow back to streams (Naiman and Decamps 1997). Complex soil environments within riparian ecosystems support anoxic and oxic biogeochemical processes that remove pollutants from water and control the cycling of nitrogen, phosphorus, and other elements and compounds (Lowrance et al. 1984; Peterjohn and Correll 1984; Brinson et al. 1995; Pinay et al. 1999).

Wetlands provide habitat for obligate and facultative wetland and riparian plants (Reed 1988) and animals. For example, in Colorado, more than 40% of all plant species occur in wetlands (D. Cooper, unpub. data 2003). A large proportion of birds (Knopf 1985), including all waterfowl and shorebird species, endangered birds such as the southwestern willow flycatcher (Finch and Stoleson 2000), and many mammals utilize wetlands during some portion of the year and many are critically tied to wetlands (Bayha and Schmidt 1983; Weller 1987). Wetlands provide forage for domestic livestock and wet meadow ecosystems are critical for the livestock industry and rural economic stability and prosperity (Clary and Webster 1989).

From the time of the early settlements in the 1800s to the 1980s most western states have lost a large percentage of their wetlands due to human activities, such as wetland drainage and water diversions. Colorado has lost 50% of its natural wetlands, Kansas 48%, Wyoming 38% and Nebraska and South Dakota each 35% (Dahl 1990). In addition, there has been a systematic conversion of riparian forest and shrub-dominated ecosystems to unvegetated and herbaceous dominated wetlands resulting in loss of habitat, particularly for migratory birds (Dahl and Johnson 1991). The greatest losses have been in riparian forest ecosystems due to river flow management; however, in central Nebraska cottonwood forests have increased due to river management (Johnson 1994).

Riparian and Wetland Ecosystem Types

Five major riparian and wetland ecosystem types that occur in Region 2 include:

(1) Riparian areas;
(2) Fens;
(3) Marshes;
(4) Wet meadows; and
(5) Salt flats.

Each of these ecosystem types form within distinctive landforms driven by different hydrogeologic processes and support unique biodiversity elements. The wetland types have many regional names, which are summarized in Table 3.1 and described below.

Riparian ecosystems occur on the floodplains of perennial and intermittent streams of all sizes (See Photos 3.7 - 3.16 and Figs. 3.4 - 3.7).

Table 3.1. Common Wetland Terms

Type	Regional Wetland Types or Nomenclature
Riparian	Riparian, bosque, spring, seep, floodplain, swamp
Fens	Fens, peatlands, bogs, moors, muskeg
Marshes	Marsh, playa, vernal pool, prairie pothole, pond
Wet Meadows	Hay meadows
Salt Flats	Flats, halophytic plant communities, inland salt marsh, salt pan, playa

Photo 3.7. Subalpine fen and wet meadow complex (see Figs. 3.4L-M and 3.7F-I).

Photo 3.8. Subalpine willow riparian area.

Photo 3.9. High mountain Engelmann spruce dominated riparian area (see Fig. 3.7A).

Photo 3.10. Subalpine spring and fen complex (see Figs. 3.4E and 3.7B).

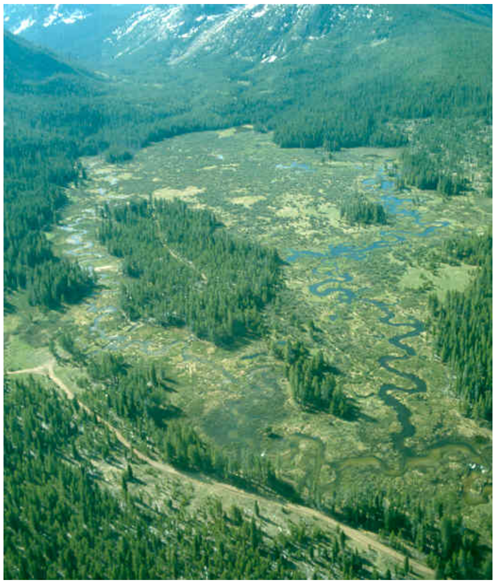


Photo 3.11. Montane riparian willow and fen complex behind a terminal glacial moraine.

Photo 3.12. Montane willow riparian complex along low gradient stream.

Photo 3.13. Mid-elevation stream with beaver complex and willow riparian vegetation.

Photo 3.14. Mid-elevation stream with willow riparian vegetation and a lodgepole pine invasion.

Photo 3.15. Mid-elevation moderate gradient stream with river birch and alder dominated riparian zone.

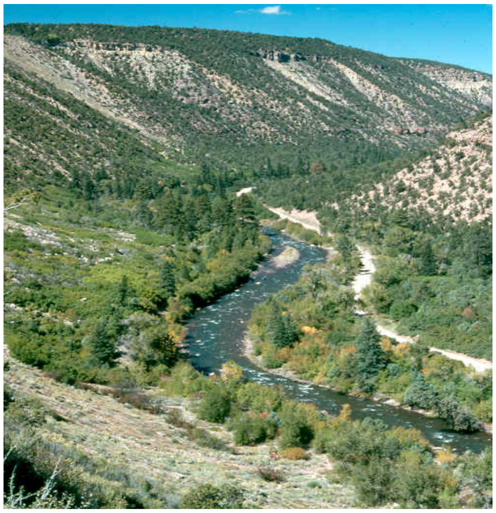


Photo 3.16. Blue spruce, narrowleaf cottonwood, and alder riparian complex along a low elevation stream (see Fig. 3.7J).

Photo 3.17. Mid-elevation natural pond with fringing marsh vegetation.

Photo 3.18. Montane wet meadow complex is utilized for pasture and hay production (see Fig. 3.5D).

Photo 3.19. Plains wet meadow supported by high water table (see Fig. 3.6C).

Riparian areas are tied together by the presence of flowing water that can erode and deposit sediment. Streams may be fed largely by snowmelt from the high mountains (Figs. 3.4E, 3.4L, 3.4M, and Photos 3.7, 3.10), or they may be groundwater fed as in the Nebraska Sandhills (Novacek 1989).

Many riparian ecosystems are structured and function based upon periodic or annual flood pulses (Friedman et al. 1997) and the life history characteristics of most riparian plants are tied to disturbance regimes (Scott et al. 1997). In addition, the distribution of communities is controlled by hydrologic and temporal gradients (Auble et al. 1994; Friedman et al. 1996). At high elevations, streams are small and riparian vegetation consists of herbaceous plants and short-stature willows (Fig. 3.7B and Photo 3.10) (Cooper 1986) or Engelmann spruce along high energy streams (Fig. 3.7A and Photo 3.9). In middle elevations of the mountains, blue spruce, tall willows, alder, river birch, and narrow-leaf cottonwood, dominate stream banks and floodplains (Fig. 3.7J and Photos 3.8 and 3.11 - 3.16) (Kittel et al. 1999; Carsey et al. 2001). Along low elevation foothills and plains streams, riparian areas are dominated by plains cottonwood and peach-leaf willow (Figure 3.5A) (Snyder and Miller 1991), with American elm and ash along many plains streams in the eastern portion of the study area (Johnson et al. 1976). The exotic plants Russian olive or tamarisk now dominate many low elevation riparian areas throughout the region (Olson and Knopf 1986; Shafroth et al. 1995).

Fens occur where perennial groundwater discharge occurs on the time scale of millennia and where little erosion or mineral sediment deposition occurs (Cooper 1990). Fens typically occur at the toes of mountain slopes (Photo 3.20) and alluvial fans, and in kettles within moraines (Photo 3.22) where the water table is at the soil surface (Figs. 3.7F-I and Photos 3.7 and 3.9). Fens have organic soils, classified as histosols (Soil Survey Staff 1975). A majority of fen plants in our region are widespread boreal species at their austral limits in North America (Cooper 1996; Cooper and Sanderson 1997). Fens are carbon sinks, (Chimner et al. 2002) important filters of water, produce important forage for native mammals, and may have shallow pools that support aquatic invertebrates and amphibians. A wide range of fen types occur based upon site elevation and thus potential flora, hydrologic regime, and the chemistry of inflowing water. Extremely rich fens occur where water pH is greater than 7.0 and high concentrations of Ca^{++} occurs (Cooper 1996), while transitional rich fens occur on acid soils (Cooper and Andrus 1994). Iron fens occur in strongly acid sites (Cooper and Arp 2002).

Marshes form in depressions, including lake margins, where deep standing water occurs at least seasonally (Fig. 3.6F and Photo 3.21). Maximum water depth can be from 20 to 200 cm, yet many marshes are dry in late summer and during drought years marshes may remain dry. In mountain areas, marshes may fill with snowmelt runoff (Photo 3.17), but in other areas intense rainfall or snowmelt events may fill basins where marshes have developed. Marshes in dune complexes (Fig. 3.5E) may have perennially high water tables. Water levels and groundwater flow patterns to or from the marshes may vary tremendously from year to year (Rosenberry and Winter 1997), and vegetation composition will also vary (Van der Valk and Davis 1978; Weller 1987) depending upon the current and past years' hydrologic regimes.

Photo 3.20. Sloping fen fed by groundwater from hill to right of photo, dominated by sedges and willows.

Marshes vary widely in the chemical content of their waters, especially regarding nutrients and soluble salts (LaBaugh 1989). Very high primary production of both plants (cattails, bulrush, spikerush, sedges and grasses) and animals (muskrats, birds, aquatic, and invertebrates) typically occurs (Kantrud et al. 1989a,b). Marshes provide critical habitat for wading and fishing birds, waterfowl (Swanson et al. 1989), shorebirds and reed-dwelling birds, as well as many amphibians and aquatic invertebrates (Murkin 1989).

Many marshes are terminal sumps (Figs. 3.5G, 3.6D, 3.6G), may occur in agricultural landscapes, and perform important sediment and nutrient removal functions (Neely and Baker 1989). Marshes have various names including playas on the southern Great Plains (Figs. 3.5I, 3.6D) (Bolen et al. 1989), prairie potholes on the northern Great Plains (Kantrud et al. 1989b), and vernal pools in the far west (Zedler 1987).

<u>Wet meadows</u> have developed where seasonally saturated soils occur but perennially high water tables or seasonally deep water do not occur (Fig. 3.6C). Wet meadows are dominated primarily by short herbaceous monocots including species of grass, sedge, and rush, and are the most important producers of forage for domestic livestock (Photo 3.19). Some wet meadow complexes have been created or enhanced by the application of irrigation water (Fig. 3.5D and Photo 3.18). This is the most widespread wetland type in the West, particularly in intermountain basins and on the plains, but it is the wetland type that we know the least about.

<u>Salt flats</u> have developed in terminal sump basins that dry out each year (Figs. 3.5K and 3.6E, Photo 3.23), or where the water table is near the soil surface and where high soil salt concentrations have accumulated (Photo 3.24). Surface water rarely flushes salts from these soils. Evaporation of water in basins may lead to the accumulation of very high soluble salt concentrations (Ungar 1974). There is considerable variation in the geochemistry of salts present and soil pH may range from 7.0 to >10.0. Salt flats typically have sparse plant cover, due to high pH and salt concentrations. However, they may support very high aquatic invertebrate and algae production when sites are inundated.

Photo 3.21. Plains marsh complex with zonation of plant communities around a water body (see Figs. 3.5G, 3.6D and 3.6G).

Photo 3.23. Unvegetated plains salt flat (see Figs. 3.5K and 3.6E).

Photo 3.22. Kettle basin with floating peat mat, sedges, and pond lilies.

Photo 3.24. Salt flat dominated by alkali sacaton.

Figure 3.4(A-N). Drawing of the mountains and plains with aquatic, riparian, and wetland areas designated. Some of the labels on the drawing are discussed in the text. (Illustration drawn by Judy Dersch)

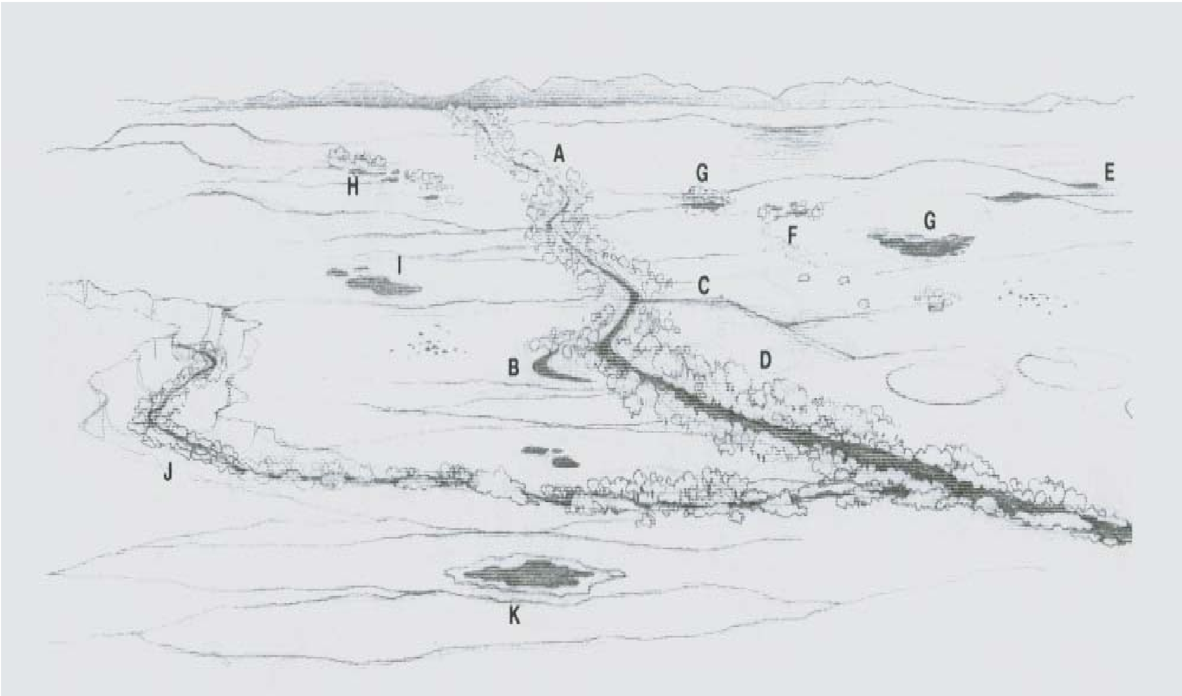


Figure 3.5(A-K). Drawing of the plains with aquatic, riparian, and wetland areas designated. Some of the labels on the drawing are discussed in the text. (Illustration drawn by Judy Dersch)

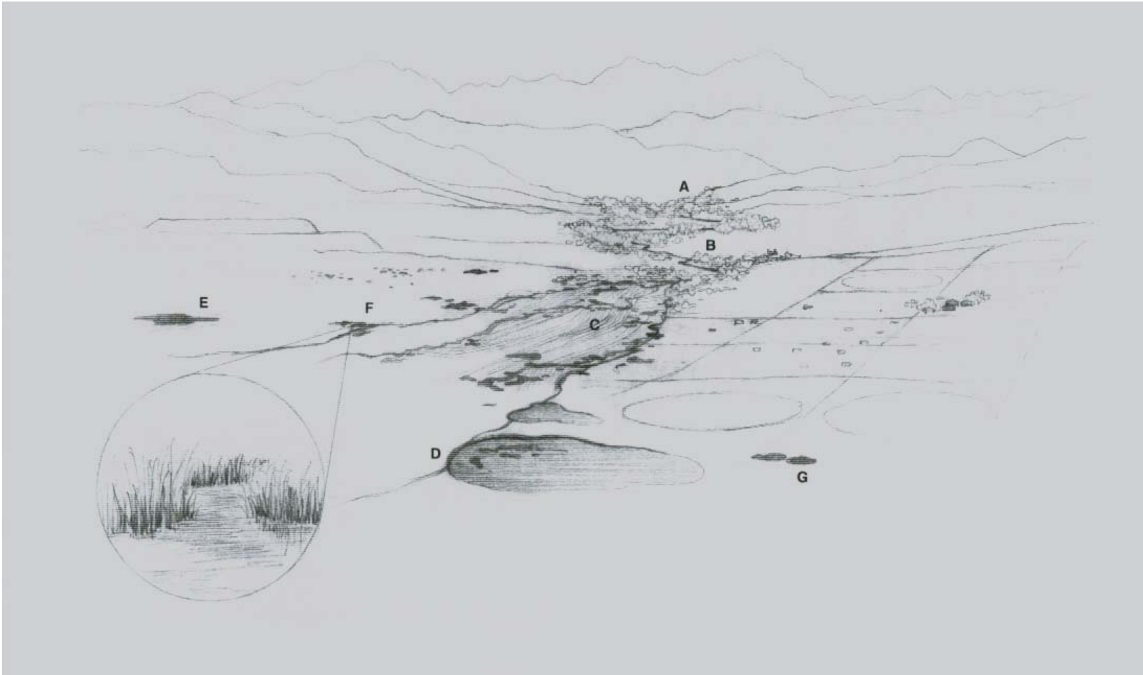


Figure 3.6(A-G). Drawing of a river basin with aquatic, riparian, and wetland areas designated. Some of the labels on the drawing are discussed in the text. (Illustration drawn by Judy Dersch)

Figure 3.7(A-L). Drawing of the mountains with aquatic, riparian, and wetland areas designated. Some of the labels on the drawing are discussed in the text. (Illustration drawn by Judy Dersch)

Critical Drivers of Riparian and Wetland Ecosystems

The most important factor controlling riparian and wetland ecosystem form and function is water table dynamics and the hydrogeologic regime. This includes the timing of surface water arrival or high water table development, seasonal or interannual variability in water delivery, water depth, the energy and materials carried by moving water, as well as water chemistry (Brinson 1981; Brinson et al. 1995).

For riparian areas, the most important physical factor is flooding, including annual and interannual variability in flooding, as well as sediment erosion and deposition. For fens, the presence of stable perennially high water tables and the absence of physical disturbance is critical. In addition, fen biota are very sensitive to water chemistry, while riparian biota are less influenced. For marshes, the presence of periodically deep water and periodic drought controls the vegetation composition, soil seed banks, and aquatic productivity. For salt flats it is the hydrologic regime - landform interaction that drives salt accumulation processes.

Each of the major wetland types in Region 2 functions within a range of hydrologic, geomorphic, and geochemical characteristics, and yet there is great ecological variability within each type driven by elevation and temperature gradients, available flora and fauna, localized landforms and watershed scale hydrologic and geochemical processes, as well as past and present anthropogenic activities.

Natural vs. Anthropogenic Disturbances

Disturbance is any process that can mobilize sediment, erode or deposit material, harm some organisms, or change the physical landscape. Fluvial disturbances are critical to the natural functioning of most riparian ecosystems. The creation of new landforms due to point bar or island formation, channel avulsion, and overbank sediment deposition is critical for the establishment of many riparian plants, such as cottonwood trees (Scott et al. 1997). While this type of disturbance regime is critical for riparian-wetland functioning, exactly the opposite is critical for the formation, persistence, and maintenance of fens. Fens occur only where little sediment deposition and erosion occurs on the time scale of millennia. Marshes and wet meadows also have limited disturbance regimes comparable with most riparian ecosystems yet they are isolated from streams or serve as terminal basins for streams. Marshes and salt flats are disturbed by periodic high water periods when plants drown and more commonly by multi-year droughts, which lead to wetland plant death.

The most significant anthropogenic disturbances on a system basis are changes in surface and groundwater flows. The regulation of river hydrologic regimes due to dam construction (Dynesius and Nilsson 1994), water diversions that deplete streams (Cooper et al. 2000; Woods 2000), or water imports that increase stream flows (O'Neill et al. 1997), ditching (Cooper et al. 1998), peat mining (Cooper and MacDonald 2000), and groundwater pumping (Cooper et al. 2002) can control the structure and function of riparian ecosystems. Interruption of groundwater flow systems or increases in sediment fluxes from hill slopes to valley bottoms can alter wetlands, such as fens, that are sensitive to increased sediment deposition or small changes in their hydrologic regime. This is likely to occur from roads that intercept surface and groundwater flow systems and channel them to other parts of the watershed, or erosion from roads, gravel mines, and timber operations. Metal pollution from historic hard rock mines is a local problem that affects montane wetlands in some watersheds (Arp et al. 1999). Marshes and salt flats that occur in terminal sump basins are affected by water diversions in the streams that affect them. Livestock grazing and mowing for hay production can affect wet meadows, marshes, and especially affect ground nesting bird communities.

Information Needs for the Different Ecological Scales

Basin Scale

Information needed at the basin scale includes the following:

(1) Maps identifying the major elevation ranges and terrestrial ecosystems, maximum altitude of mountains, and the presence of snow accumulation basins.
(2) Identification of bedrock types within the region. Most critical is the presence of high elevation outcrops of limestone and dolomite and overall bedrock and geochemical complexity.
(3) Maps identifying glaciated regions and the extent and distribution of moraine and till deposits.
(4) Hydrologic characterization of the basin.
(5) Identification of the presence of endemic or widely disjunct species. This is very important for species restricted to one basin due to biogeographic and historical factors.

Wetland and riparian biota differ from basin to basin across Region 2 based upon climate differences and biogeographic history (Cooper 1996). The main differences are from north to south. In the north, elements of the boreal flora are more prevalent; for example in the Wind River and Yellowstone region, elements of the Pacific Northwest floristic elements are common in wetlands (e.g., *Phyllodoce empetriformis*) (Cooper and Andrus 1994). Several amphibians reach their austral limits in Region 2 (e.g., *Rana sylvatica*) (Hammerson 1986). Elements of the Chihuahua Desert and Mexican highlands flora are characteristic of wetlands in southern Colorado. Elements of the Siberian/East Asian flora are also common in South Park, Colorado salt flats (e.g., *Thellungiella salsuginosa*) (Weber and Wittmann 1998). Throughout the region, plants that are disjunct by 1,000 km or more from the main ranges of their species are common, yet may have a very localized distribution at the basin scale (e.g., *Carex tenuiflora* in the Tarryall Mountains of Colorado). The persistence of these disjunct species provides a distinctive element to the wetland flora, particularly in fens, marshes, and salt flats.

Bedrock type, weathering, erosion, precipitation regime, and glaciation controls the chemical content of surface and groundwater, upland vegetation cover, and therefore, sediment production. Limestone and dolomite, as well as some shale and volcanic rocks, produce alkaline waters high in carbonates, whereas granites, sandstones, and metamorphic rocks produce acidic waters low in mineral content. Fen plants derive all of their mineral ions and nutrients from their water supply since plant roots are not in contact with the underlying mineral soils. Therefore, water chemistry produces the main regional scale gradient in fens in the Rocky Mountain Region (Cooper and Andrus 1994). Bedrock type and the liberation of salts may influence where salt flats develop.

Landscape Scale

Information needed at the landscape scale includes the following:

(1) Maps identifying the zone of Pleistocene glaciation, as well as riparian and wetland maps. The U.S. Fish and Wildlife Service's National Wetlands Inventory maps are available for many parts of the region, and provide a first approximation of wetland distribution. Some National Forests have conducted detailed riparian surveys and have produced riparian classifications and maps (e.g., Bighorn Mountains, Girard et al. 1997).
(2) Characterization of the wetland types occurring in each region.
(3) Maps identifying the location of rare or sensitive species and information on the hydrologic and geomorphic processes supporting the wetlands where these species occur.
(4) Identification of the natural disturbance regimes that create the diversity of wetlands in the landscape.
(5) Identification of existing or potential projects (e.g., dams, water diversions, and road networks) or proposed activities (e.g., logging or road construction) that could or have changed the hydrologic regime of

streams, hillslope groundwater aquifers, sediment movement in streams, sediment fluxes from hillslopes to valley toe-slopes or valley bottoms.

Air and soil temperature change with increasing elevation, as does precipitation, which drives landscape scale patterns of plants and animals. In addition, evapotranspiration rates decrease with increasing elevation, increasing the abundance of water. Consequently, the aerial coverage of wetlands can increase markedly with increasing elevation, particularly in basins just below the upper treeline. The presence of landforms that retard the drainage of water from basins exerts a large influence on the abundance of wetlands, and the types of wetlands that occur. The most important are live and dead ice deposits from Pleistocene glaciers, which have dammed up valley bottoms or created landscapes with poorly developed drainage networks that can support extensive wetland complexes.

An inventory of wetland and riparian types in the basin would provide an overview of the hydrologic, geomorphic, and ecological diversity at this scale. National Wetland Inventory (NWI) maps provide some information but the Cowardin classification (Cowardin et al. 1979) used by NWI places most wetlands in our region into the palustrine system and NWI maps tend to underestimate the area of wetlands in mountain regimes.

Local or regional inventories and classifications can provide the best information for analyzing regional diversity. Cooper (1986) proposed an alternative wetland classification system and now statewide riparian and wetland classifications are being developed (e.g., for Colorado; Kittel et al. 1999; Carsey et al. 2001).

At the landscape scale, hydrologic characteristics are the critical drivers. The presence of high mountains that accumulate a large winter snowpack, which produces an annual snowmelt-driven spring flood pulse may support floodplains with well-developed riparian vegetation. Basins or tributary streams without connection to high snowpack watersheds will have small or no spring floods and summer rainstorms may provide the key natural disturbance, which is stochastic. The functioning of snowmelt-driven streams with a more predictable, single annual flood is distinct from that of groundwater fed or rain fed streams. In addition, since most water for low elevation streams and riparian zones originates from high elevation basins, the chemical content of the water may be determined by the lithology of upper basin bedrock. For example, high elevation limestone outcrops may create calcareous waters throughout the watershed. If this water flows downstream through a granite basin, the water chemistry may still be controlled by upstream chemical contributions.

Management Scale

Information needed at the management scale includes the following:

(1) Identification of wetland types occurring in the watershed. This should include characterization of the hydrologic, geomorphic, and geochemical regimes of each type and their locations.
(2) Identification of the extent of each wetland type within the watershed. This can be used to identify the rare and common community types in each watershed.
(3) Identification of the area of wetland in 6th level HUBs based from riparian maps. This can be used to identify where in the watershed disturbances could affect the largest area of wetlands.
(4) Identification of wetlands dominated by exotic plants.
(5) Identification of specific wetland types supporting rare plants or animals (e.g., boreal toad breeding pools). Rare plants at this scale can be federally or state-listed or species of regional importance e.g., the most southerly population of a plant or animal in North America or populations that are widely disjunct from their main ranges and irreplaceable if destroyed. An example is *Sphagnum balticum*, a peat moss common in the subarctic, but found in the lower 48 United States only on a one-hectare fen in

SW Colorado that has unique geochemical characteristics (Cooper et al. 2002).

Within a 6th level HUB there may or may not be variations in climate that affect the distribution of biota. Riparian wetlands will typically occur along all perennial and some intermittent streams and their characteristics will be controlled by elevation, stream gradient, floodplain width, and the stream hydrologic and geomorphic regime. Individual wetlands also will be present where particular ground and surface water systems occur.

Reach/Site Scale

Information needed at the reach/site scale includes the following:

(1) Information on the exact locations of wetlands and the types present.
(2) Data on the biotic composition of wetlands and the drivers that create and support these wetland types.
(3) Location information for rare biota.
(4) Reach/site information on the hydrologic regime or sediment regime of wetlands.
(5) Reach/site information on the effects of roads or hydrologic alterations on wetlands.

Aquatic Invertebrate Resources

Invertebrates play an important role in the healthy functioning of aquatic ecosystems. They are a highly diverse group that provides the foundation for fish production in streams, rivers, and lakes. Much of the animal species diversity of aquatic ecosystems is attributable to invertebrates. In streams and small rivers, the majority of this diversity derives from the juvenile forms of aquatic insects (Hynes 1970; Ward 1992), although small non-insect invertebrates can be important in streambeds comprised of fine sediments (e.g., Hakenkamp and Palmer 2000).

In standing waters such as lakes, planktonic crustacean species are important (Ward 1992). In streams and small rivers, the diversity and species composition of aquatic insects is a primary consideration in the management of water quality and ecological health (Rosenberg and Resh 1993), because the environmental requirements and sensitivities to pollutants and habitat degradation for many species and/or species complexes are well known. Many state water quality regulations are based on ecological characterization of aquatic insect diversity and species composition. The distribution and abundance of aquatic invertebrate species varies with many environmental factors ranging from small-scale habitat conditions to geographic variation in climate. Accordingly, the expected or potential invertebrate diversity for an aquatic ecosystem will depend on the scale at which an assessment is conducted.

Invertebrate Diversity and Primary and Secondary Production

Invertebrates provide a primary consumable resource that supports the production of fish (and higher trophic levels) in aquatic ecosystems and their linked terrestrial systems (Nakano and Murakami 2001). Aquatic habitats that produce more invertebrates can generally support greater biomass in higher trophic levels, such as fish (Benke 1993; Poff and Huryn 1998) but not all invertebrates are equally consumable by fish predators, due to variation among species in behavior or morphology (Wootton et al. 1996; Rader 1997). Therefore, factors that control community composition of invertebrates may also influence production available to higher trophic levels. Accordingly, the production potential of streams can be assessed at a variety of hierarchical spatial scales (Poff and Huryn 1998).

Invertebrate production is fueled either by energy contributed to the stream from the terrestrial environment (allochthonous) or energy produced within the stream by *in situ* primary production (autochthonous) (Benke 1984). These sources differ in some important characteristics, such as particle size, chemical composition, and seasonal availability, which together can influence overall secondary production and invertebrate diversity. Therefore, an important component of an aquatic assessment is to characterize the relative contributions of these two types of energy sources (for a specified scale) and to evaluate what the total allochthonous and autochthonous energy contribution to the system is.

The River Continuum Concept (Vannote et al. 1980) lays out how sources and types of energy vary along river courses, in response to natural physico-chemical gradients (Fig. 3.8). These energy source types can vary greatly along river courses in response to natural physico-chemical gradients. Headwaters are generally considered to be allochthonous and support invertebrates, such as shredders, that rely on coarse particulate inputs (Vannote et al. 1980). Typically, *in-situ* primary production dominates in so-called mid-reaches of streams, which correspond to roughly order 4-7 using the classification scheme of Strahler (1952). In these reaches, the streambed is not completely shaded by riparian canopy and light can penetrate to the bottom given low turbidity and relatively shallow water. Here, algivorous grazers (or scrapers) can comprise a significant component of the invertebrate fauna. In these mid-reaches, invertebrate diversity (if not production) is theoretically highest, in part due to the combination of allochthonous and autochthonous energy sources that support a variety of invertebrate feeding strategies (Vannote et al. 1980).

However, these patterns can be modified under particular environmental settings. For example, headwaters can be primarily fueled by autochthonous energy (algae) if they are unshaded, as is often the case in high elevation western streams (Minshall 1978). And, human perturbation can modify riparian inputs of allochthonous materials as well as light availability to the streambed through removal of streamside shading or altered turbidity (Allan 1995; Karr and Chu 1999).

Primary production *per se* is difficult to measure. Algal standing crop (or biomass) can be used as a surrogate for primary production and it represents the integrated response to a number of processes that increase biomass (nutrients, light, temperature) and those that reduce it (disturbance by scouring or overturning of stones by high velocities and grazing) (Biggs 1996). The balance of these processes can vary greatly from place to place and reflect local limiting factors. So, for example, even high sunlight in alpine streams may not support much algae if nutrients are limiting. Sources of nutrients, such as carbonate rocks can increase primary production in otherwise nutrient limited waters (e.g., Hill and Webster 1982).

Algal standing crop does not necessarily indicate resource quality to secondary consumers, because algal species differ in their food quality. For example, low biomass algal mats comprised of diatoms can support up to twenty times their biomass in insect grazers due to their high nitrogen content and fast generation times (Allan 1995). High biomass mats consisting of filamentous algae or moss are not as productive as diatoms, and they provide poor quality food for most invertebrates. Human alterations such as riparian clearing can increase primary production and result in a greater standing crop of invertebrate grazers (e.g., Wallace and Gurtz 1986).

Information Needs for the Different Ecological Scales

Basin Scale

Information needed to identify invertebrate characteristics at the basin scale includes the following:

(1) Identify the freshwater ecoregions (sensu Maxwell et al. 1995; Abell et al. 2000) contained within the forest.
(2) Characterize the relative levels of invertebrate species richness and dominant families of invertebrates within each ecoregion.
(3) Identify natural processes that influence invertebrate distribution patterns at this scale. Examples include zoogeographic factors and climatic gradients in seasonal temperatures.
(4) Identify anthropogenic processes that influence or could potentially influence invertebrate diversity or production at this scale. Examples include global climate change or atmospheric deposition.

Variation in the diversity and production of invertebrates varies naturally at this large geographic scale. Thus, the diversity or production of any local site (e.g., within a particular forest unit) will depend to some degree on the basin level characteristics. Chief among these are zoogeographic history and climatic gradients in seasonal temperatures.

Because aquatic insects have winged adult stages, river basin divides may not restrict the distribution of these invertebrates to individual watersheds (Bunn and Hughes 1997). Lake-dwelling invertebrates typically have resistant eggs or other resting stages that allow them to be transferred (via wind, or assisted by mobile animals) between basins (Pennak 1978). Aquatic insect species distributions often show more similarity among biomes within similar habitats than across habitats within a biome (Corkum 1990; 1992). However, watersheds isolation can contribute to genetic variation within species among watersheds (Bunn and Hughes 1997, Hughes et al. 1999).

River basins in Region 2 tend to drain along an east-west axis and therefore are separated latitudinally. Northerly basins experience a colder climate than southerly basins, such that as one progresses northward, water temperatures are seasonally cooler. Seasonal water temperatures affect temperature-dependent ecosystem processes (such as decomposition rates) and species distributions. Species have geographic centers of distribution that largely reflect specific adaptation to seasonal thermal regimes (Vannote and Sweeney 1980). Shifts in the population abundance of invertebrate species therefore occur along large-scale north-south thermal gradients. Also, because metabolic and developmental rates of invertebrates are temperature-dependent, secondary production should generally decrease along a south to north gradient (Sweeney 1984; Benke 1993).

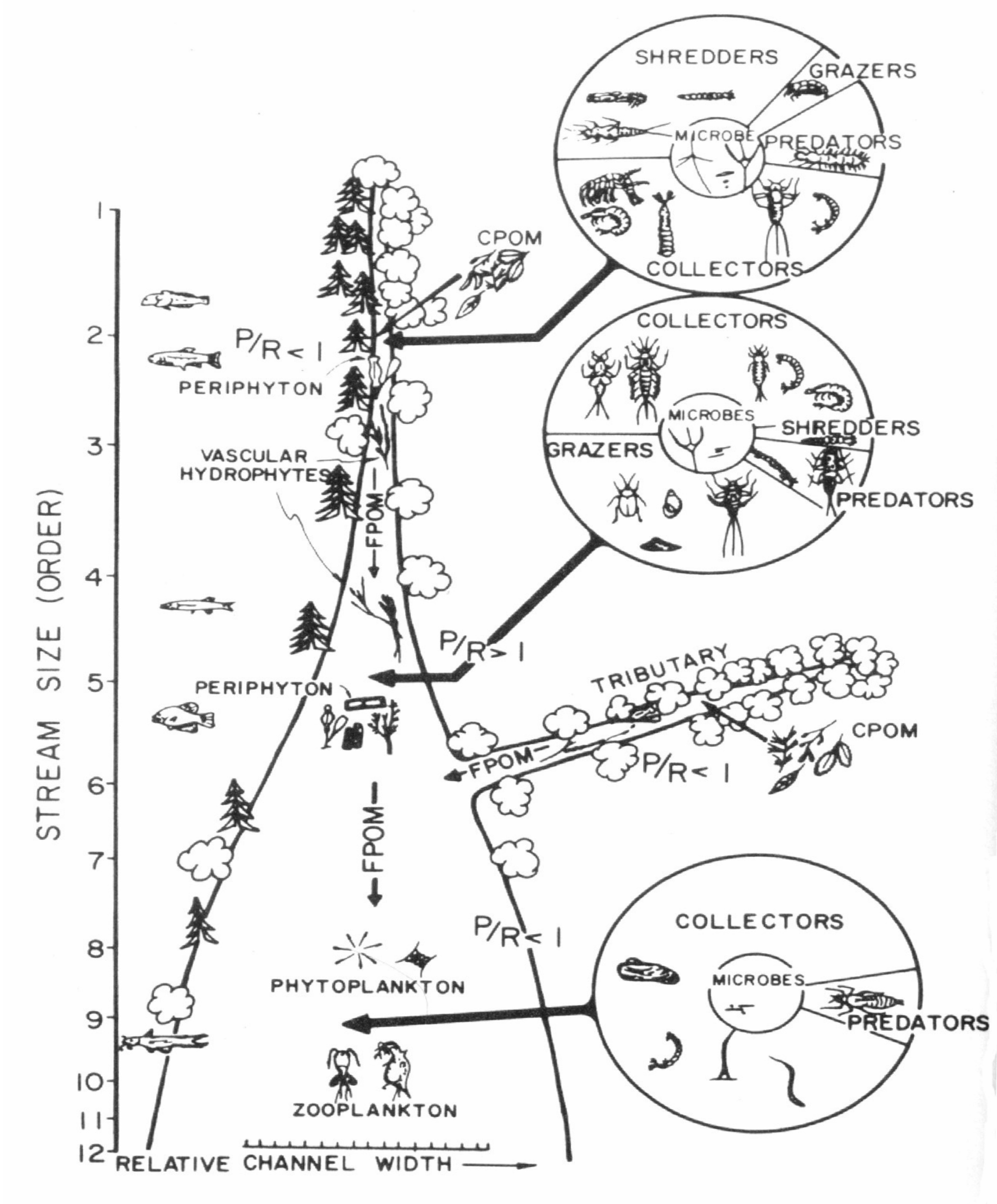


Figure 3.8. The River Continuum Concept (from Vannote et al. 1980).

Unfortunately there is no reliable, detailed characterization of invertebrate diversity or production at the basin scale for Region 2. It should be possible to characterize the distribution of major taxa based on geographic collection records. These could be used to generate basin-specific maps of expected invertebrate taxa.

Landscape Scale

Information needed at the landscape scale for invertebrates includes the following:

(1) Identification of the natural processes that influence invertebrate distribution patterns. These include climate zones that determine stream thermal conditions, hydrologic regimes that determine streamflow patterns, major vegetation zones that influence stream habitat conditions, and surficial geology that determines water fertility and sediment supply and transport.
(2) Identification of anthropogenic processes that influence invertebrate distribution patterns. These include alterations in water, sediment and nutrient flux through stream channels, caused by land management practices and by on-channel impoundments that disrupt upstream-downstream linkages in streams.

The thermal regime is the seasonal variation in temperature, including both extremes and rates of change between these extremes (Ward and Stanford 1982). At this scale, thermal regime primarily reflects differences in elevation. Temperature conditions are critical determinants of the growth and developmental rates of ectothermic invertebrate species (Vannote and Sweeney 1980; Ward and Stanford 1982). Many lotic insects predictably emerge as adult forms from the water when a certain threshold of temperature accumulation has occurred over time; therefore the same species may exhibit variation in growth, development rates, and in emergence timing as a function of altitude (Ward 1992). Aside from total thermal accumulation, other components of a thermal regime can be important, including annual range of temperature and rate of change in temperature during spring and autumn. The distribution and abundance of many aquatic insect species within a drainage is determined by temperature. There is a distinct "altitudinal zonation" in Rocky Mountain streams, directly reflecting the thermal conditions prevailing at those altitudes (Ward 1986; Ward and Kondratieff 1992; Hauer and Stanford 1982). These thermal conditions change relatively predictably with elevation. In high elevation or northerly streams, heavy ice cover in winter can result in a rapid breakup during the spring. Ice scour of the bed can reduce benthic populations (Hudon 1994).

Productivity of aquatic invertebrate communities is generally higher in warmer waters (Ward 1992; Benke 1993), because metabolic rates for ectotherms are increased. Such increases in productivity may not necessarily be transferred up the food chain, however. For example, microbial decomposition rates of detritus also increase with temperature, reducing the quantity of such detritus for macroconsumers (Meyer and Edwards 1990). Aquatic invertebrates may also have faster life cycles but be reduced in size, perhaps at the expense of size-selective vertebrate predators. Production of individual species can change with elevation in Rocky Mountain streams (Rader and Ward 1987).

The hydrologic regime determines how much water is in the channel at any given time. Drying of streams (intermittency) has severe consequences for aquatic communities, severely reducing diversity and limiting production (Larimore et al. 1959; Stanley et al. 1997). Perennial streams flow year-round and in this region higher elevation streams receive their runoff from seasonal snowmelt. Thus, they have a predictable period of high and low flow that influences many ecosystem attributes (Poff and Ward 1989).

Streams that head at lower elevations (e.g., foothills and plains) are not likely to be seasonally influenced by runoff from rainfall, which may provide the main source of streamflow. These systems tend to be more temporally intermittent during periods of low precipitation, because they lack the storage characteristic of snowmelt streams. Thus, lower elevation streams may have a very different fauna due to seasonal drying and to late-season disturbance (in addition to other factors, such as warmer summer water temperature).

During high flow events, sediment is transported and this often serves as a source of disturbance that induces mortality in benthic invertebrate populations (Resh et al. 1988; Poff 1992) and scours benthic algae (Peterson 1996; Peterson et al. 2001). The frequency and timing of bed movement influence the types of species that occur in a system. For example, frequently disturbed streams are dominated by highly mobile species that are good at recolonization (Scarsbrook and Townsend 1993; Richards et al. 1996; Townsend et al. 1997a; Robinson and Minshall 1998). Invertebrate diversity can be maximal at intermediate levels of disturbance (Townsend et al. 1997b), possibly because weedy species are not eliminated by their competitive superiors, which are more severely reduced in abundance by disturbance (Hemphill and Cooper 1983; Hildrew and Giller 1994; Townsend et al. 1997a). Interannual variation in population sizes for lotic species can also be attributed to interannual variation in disturbance or other environmental conditions (Feminella and Resh 1990; Voelz et al. 2000). High flow disturbances also have a direct influence on invertebrate production, because mortality reduces population size and thus biomass.

Surficial geology regulates the types and quantities of nutrients available for dissolution and also influences stream thermal and flow regime. Invertebrate production is generally higher in streams draining calcareous lithology, due to a combination of greater dissolved nutrients and more stable thermal and flow regimes (Krueger and Waters 1983; Huryn et al. 1995). High elevation streams typically drain nutrient-poor granitic bedrock and are expected to have a lower relative production potential.

Disturbance is generally viewed as a critical determinant of invertebrate diversity and production (Resh et al. 1988). The central role of disturbance in stream ecology is illustrated in Figure 3.9 (Resh et al. 1988). The importance of disturbance has been recently highlighted in the coining of the term "process domains" (Montgomery 1999), which refers to natural landscape variation in disturbance regime in streams that reflects physiographic setting (lithotopo-units). Channel bed stability and characteristic rates of movement during high flows reflect the underlying geology. The importance of this has been demonstrated for Rocky Mountain streams (Gregg and Stednick 2000).

Anthropogenic alterations at this scale are primarily those that disrupt the upstream-downstream connectivity of streams and rivers especially for steep mountain regions (Montgomery 1999). Natural downstream gradients occur in physical, chemical, and biological characteristics, which reflect changes in climate, topography, geology, and aquatic-terrestrial exchange. The River Continuum Concept (Vannote et al. 1980) describes the general relationship among these variables, but streams in the Rocky Mountain Region show some deviation from the idealized pattern. Headwater streams may be heavily shaded and driven by allochthonous energy inputs utilized mostly by invertebrate detritivores or they may be relatively open (e.g., in the alpine zone) and have significant autochthonous production that supports a diversity of invertebrate feeding groups (Minshall 1978). In larger streams (generally at lower elevations), the canopy is less closed and there is a greater relative contribution of *in-situ* primary production to the stream's energy base. However, as turbidity and depth increase further downstream, primary production declines and detrital inputs again assume greater importance (Vannote et al. 1980). In larger rivers in alluvial settings, lateral connections between the channel and the floodplain can occur seasonally. These connections allow seasonal exchange of nutrients and may increase the overall productivity of large river systems (Bayley 1995; Lewis et al. 2000).

Impoundments on flowing waters alter the thermal, nutrient, and hydrologic regimes downstream of the reservoir (Ward and Stanford 1982; Poff and Hart 2002). Local warming or cooling of thermal regimes, for example by surface-release or deep-release dams, can shift the distribution of insect species to an upstream or downstream direction (Ward and Stanford 1982; Voelz and Ward 1991). In extreme cases, altered thermal regimes can cause extensive loss of diversity as thermal development cues are lost (Lehmkuhl 1974).

Storing of snowmelt flows decreases natural rate of bed disturbance, which alters habitat conditions for species below dams. The absence or altered seasonal timing of disturbance can have important consequences for the diversity for food webs (e.g., Wootton et al. 1996). Dams also capture sediment and thus change composition of streambeds downstream. This can lead to armoring and reduced disturbance rates (Collier et al. 1996).

Alteration of land cover types (e.g., deforestation) has the potential to change thermal regimes by modifying the extent to which water flows overland versus in the sub-surface to reach the stream. Deforestation can also alter hydrologic regimes by increasing water export and stream flashiness (Likens and Bormann 1974). This may result in increased rates of disturbance, including depth of scouring which can differentially affect subsurface organisms or developing fish eggs (Montgomery et al. 1999).

As with the basin scale, there is no existing, detailed characterization of invertebrate diversity or production at the landscape scale for Region 2. However, the altitudinal zonation of aquatic invertebrates is well understood for many individual basins and this information could provide a basis for generating maps of expected invertebrate taxon composition for individual Forests at the landscape scale.

Management Scale

Information needed for invertebrates at the management scale includes the following:

(1) Identification of the natural processes that influence invertebrate distribution patterns. These are the same as those described for the landscape scale at the 4th level HUB and include climate zones that determine stream thermal conditions, hydrologic regimes that determine streamflow patterns, major vegetation zones that influence stream habitat conditions, and surficial geology that determines water fertility and sediment supply and transport.
(2) Identification of anthropogenic processes that influence invertebrate distribution patterns. These include alterations in water, sediment, and nutrient flux through stream channels, caused by land management practices and by on-channel impoundments that disrupt upstream-downstream linkages in streams.

The factors identified at the landscape scale can be attributed at the 6th level HUB scale, by overlaying the maps generated at the 4th level HUB. This process will identify stream reaches within the 6th level HUB that share environmental drivers. Compared to low elevation 6th level HUBs in Region 2, high elevation HUBs are likely to be characterized by a greater diversity of environmental drivers, simply because they span a wider range of elevation, which is associated with a variety of environmental conditions.

One important constraint in applying ecological assessment at the 6th level HUB is that this land unit is not necessarily ecologically or hydrologically based. Given the hierarchical and networked nature of aquatic systems, any HUB must be referenced to the upstream and downstream setting, e.g., referenced to their parent watershed, including the headwaters where stream flow originates.

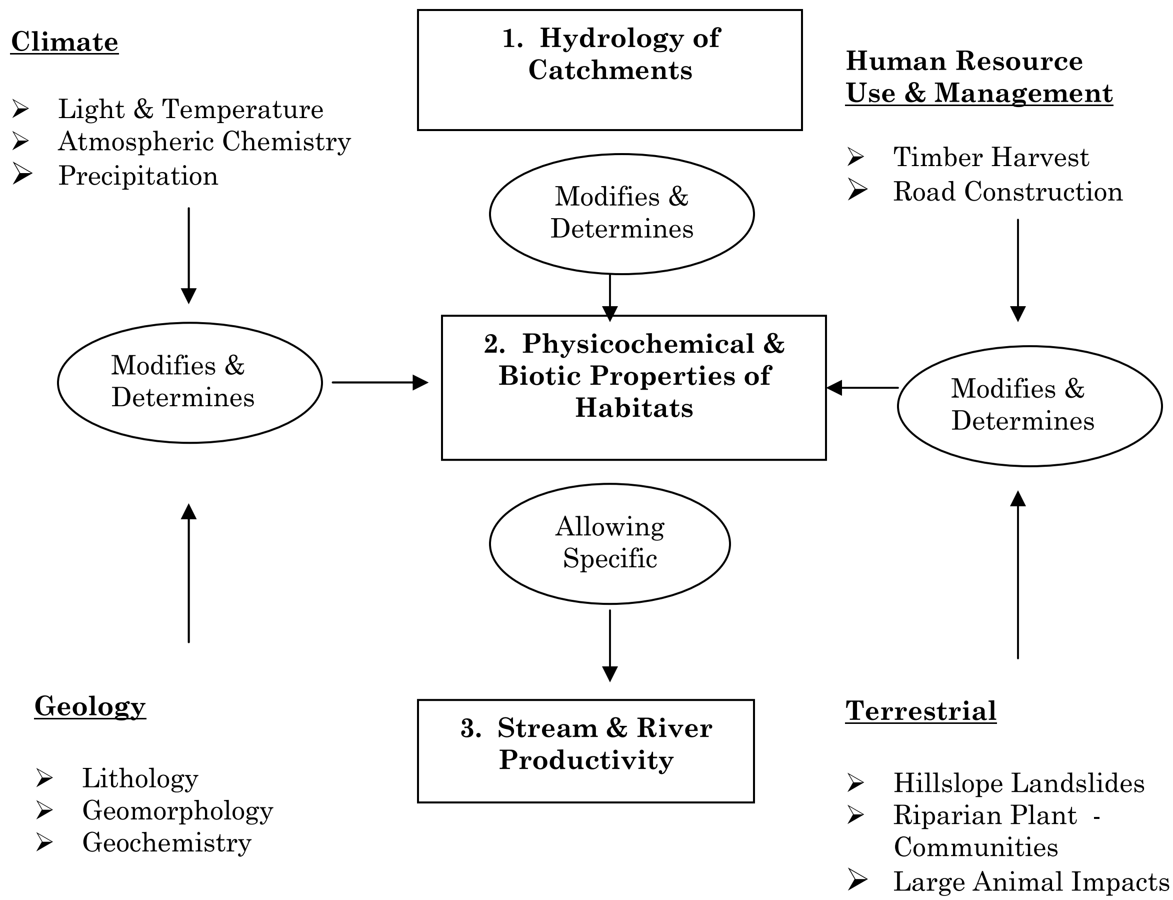


Figure 3.9. A generalized representation of abiotic and biotic factors affecting stream productivity within a catchment (after Resh et al. 1988).

The anthropogenic disturbances discussed for the landscape scale are important at the management scale as well. At the 4th level HUB cumulative effects of distributed, small-scale land use management practices can also be evaluated to assess condition of management units. For example, local water diversions can have severe effects in Rocky Mountain streams by selectively reducing the abundance of sensitive invertebrate species (Rader and Belish 2000; Poff and Pepin unpublished data). The total number of stream diversions within a 4th level HUB management unit could provide an index of cumulative local impact on invertebrate community integrity. Similarly, road density within a 4th level HUB may provide a measure of anthropogenic impact, because fine sediments from roading activities are known to degrade aquatic habitat and eliminate sensitive invertebrate species (Waters 1995). The total extent of grazing in riparian zones at the 4th level HUB could similarly provide a measure of stream channel degradation and biotic condition.

As with the basin and landscape scales, there is no existing, detailed characterization of invertebrate diversity or production at the management scale for Region 2. However, because 6th level HUBs can be reasonably assigned to combinations of altitude, geology, and hydrology, maps of expected invertebrate taxon composition, for individual Forests, should be generated at the management scale.

Reach/Site Scale

Information needed to identify invertebrate and primary production characteristics at the reach/site scale includes the following:

(1) Identification of local habitat characteristics, including substrate, channel geometry, water velocity, riparian condition, and disturbance regime. Together, these constitute the habitat structure and habitat dynamics that regulate abundance and production of primary producers and invertebrates.
(2) Identification of anthropogenic processes that modify local habitat characteristics. Land management practices that alter nutrient and sediment inputs (e.g., grazing, riparian tree removal) and flow regimes (e.g., diversions) are particularly important.

A stream reach can be defined as a length of stream channel that incorporates several local habitats, including riffles and pools. The distribution and abundance of local habitats are dictated by channel morphology and riparian conditions (Gregory et al. 1991), which reflect underlying geology and valley bottom topography (Frissell et al. 1986).

At the reach/site scale, stream width is a central determinant of food quality and quantity for invertebrates, primarily because of its effect on riparian vegetation (Vannote et al. 1980). Habitat complexity also has important influences on reach-scale patterns of invertebrate community composition and production (Huryn and Wallace 1987). Reaches that are constrained by bedrock will tend to have reduced habitat complexity and hyporheic volume, and faster through-flow of organic matter and nutrients compared to unconstrained, alluvial reaches (Gregory et al. 1991). Such "high energy" reaches are predicted to have reduced invertebrate diversity and a high proportion of low-productivity habitat (e.g., bedrock run and glide) compared to unconstrained reaches (e.g., alluvial cobble-riffle). However, an abundant cover of aquatic mosses may invert this relationship and impart a high degree of invertebrate diversity and productivity in bedrock-constrained reaches with an abundant cover of aquatic mosses (Grubaugh et al. 1997).

Water depth, velocity, and type of substrate are often used to identify spatially distinct channel features designated here as local habitats (or channel unit habitats – sensu Hawkins et al. 1993). Local-habitat type, such as riffle or pool, strongly influences the local distribution and abundance of aquatic invertebrates (Hynes 1970; Allan 1995). Invertebrate species often can be associated with particular sizes of substrate and velocity (Minshall 1978). For example, burrowing mayflies prefer fine sediments that allow excavation (Hynes 1970). Streams having more stable substrate during floods are considered to be able to support larger, longerlived organisms that have slow population recovery times (Poff and Ward 1990; Townsend and Hildrew 1994). The ability of the substrate (including woody debris) to retain organic matter (retentiveness) can also influence the abundance and production of detritivorous invertebrate species (Smock et al. 1989).

Invertebrate community diversity is generally high in streams with coarse bed materials (gravel bed streams), due to the variety of microhabitats provided (Minshall 1984; Ward 1992). Streams where fine sediments (silt) accumulate tend to have lower diversity in the sediments and a higher proportion of tolerant species of burrowing and small-bodied invertebrates (Waters 1995). Overall diversity is also higher in more complex beds, where refugia occur during scouring or bed-moving high flows (Resh et al. 1988; Lancaster and Hildrew 1993a, b; Scarsbrook and Townsend 1993; Matthaei and Townsend 2000).

Invertebrate production in high-gradient headwater streams tends to be relatively uniform among habitats, largely because of high levels of production in debris-dam pools (Huryn and Wallace 1987). By contrast, in lower gradient streams with more mobile beds, riffle habitats are usually considerably more productive than pools (Fisher 1977; Bowlby and Roff 1986; Grubaugh et al. 1997). Woody debris that retains organic matter (e.g., dead leaves) can also increase invertebrate production (Smock et al. 1989). Not only can local habitat influence the production of prey biomass, but by influencing their taxonomic community structure, this factor can also influence the relative availability of quality prey to drift feeding salmonids (Rader 1997).

Riparian vegetation influences stream diversity and production in many ways, some of which have been previously alluded to. Woody debris recruited to the channel provides habitat (Gregory et al. 1991). Inputs of leaf litter can drive stream metabolism and regulate local community structure of invertebrates (Molles 1982). Absence of riparian shading on a streambed shifts stream production toward autotrophy and shifts the invertebrate community towards species that graze algae (Vannote et al. 1980; Minshall 1978).

The intimate and complex linkages between the aquatic and terrestrial realms are becoming increasingly well understood. Export of terrestrial invertebrates to streams can be an important subsidy for fish production, especially during summer months when aquatic production is low (Mason and Macdonald 1982; Edwards and Huryn 1996; Wipfli 1997). Conversely, production of aquatic invertebrates can subsidize terrestrial insectivores (Nakano et al. 1999; Nakano and Murakami 2001; Sabo and Power 2002).

Anthropogenic alterations of local habitat that influence invertebrate communities, invertebrate production, and primary production are numerous and well documented. For example, grazing often reduces riparian cover, increases sediment loads to stream reaches, and enhances local nutrient loading. Removal of riparian forests increases sunlight to small streams and alters the autotrophic/heterotrophic nature of these channels, subsequently modifying invertebrate communities (Hawkins et al. 1982). Stream diversions reduce wetted channel habitat and eliminate seasonal dynamics of flow in reaches below the diversion structure, thereby reducing abundance and production of invertebrates (Rader and Belish 1999).

Many site-specific studies have been conducted on Forest lands in Region 2, and these can form the basis for assessments at the reach/site scale. However, care must be taken to ensure that such existing studies span the range of conditions present across the Forest. For example, studies of small streams originating at lower elevation are probably underrepresented in the region, as are studies of small alpine streams.

Fisheries Resources

Fish are important in aquatic ecosystems because of their role in ecosystem functioning and because of their recreational value to humans. In lakes, fish can affect energy transfers among trophic levels through trophic cascades whereby the relative abundance of piscivorous and planktivorous fish influences the abundance of algae and ultimately water quality (Matthews 1998). Trophic cascades also exist in streams where piscivorous fish influence the distribution of algae-eating fish, which in turn influences the abundance of algae (Power et al. 1985). Fish can import nutrients into stream systems through anadromous spawning migrations (Wipfli et al. 1999) or export nutrients to terrestrial landscapes when spawning fish are primary food sources for terrestrial carnivores such as bears and otters (Ben-David et al. 1998; Hilderbrand et al. 1999). Through predation, fish can influence the distributions of other aquatic organisms including large-bodied species of zooplankton (Matthews 1998), aquatic insects such as dragonflies (Morin 1984) and amphibians (Bradford et al. 1993). A particularly challenging issue facing managers is reconciling the public's desire to maintain fisheries in high-elevation lakes with the loss of invertebrate and amphibian populations that occur when fish are stocked into formerly fishless waters (Drake and Naiman 2000).

The recreational value of fish to humans is evident by the large number of citizens that participate in fishing. Approximately one in four Americans fishes during a given year (U.S. Fish and Wildlife Service 1999) and expenditures related to recreational fishing are a major source of tourism-related income in many communities adjacent to National Forests. Humans also value the psychological well-being and enjoyment provided by recreational fishing in a scenic environment (Weithman 1999).

Fish have a long history of being used as biological indicators of the health of aquatic ecosystems. Early work focused on the use of a few species as bioassay organisms but recent work has utilized characteristics of the entire fish assemblage to assess the biotic integrity of aquatic ecosystems (Simon 1999). Fish have been promoted as good indicator organisms for assessing the health of aquatic ecosystems because of the following factors (Simon 1999):

(1) Fish are found in most aquatic habitats and include a range of species with different tolerances to environmental stresses. They are relatively long-lived and mobile compared to taxa in lower trophic levels. Thus, fish species composition provides insights into abiotic conditions integrated over moderate spatial scales and for relatively long time periods.
(2) Fish are relatively easy to sample and the sampling frequency necessary for trend assessment is less than for short-lived organisms. The taxonomy of fish is well established enabling professional biologists to reduce sample-processing times by identifying most specimens in the field.
(3) There is extensive literature on habitat requirements, life-history characteristics, and tolerance of environmental stressors for many species. Thus, the presence and abundance of many species can be related to water quality parameters and overall ecosystem condition.
(4) Fish are highly visible, familiar, and valuable components of the aquatic community to the public. Thus, the public can relate to statements about the status of fish assemblages in relation to ecosystem condition.
(5) Results of studies using fish can be directly related to regulatory statutes such as the fishable and swimmable goal of the Clean Water Act or prevention of species extinction as mandated by the Endangered Species Act.

Many fish assemblages have been changed as a result of habitat alteration and the introduction of non-native species (Abell et al. 2000). Habitat alteration often results in the replacement of native species by non-natives that are better adapted to the changed physiochemical conditions (Moyle and Light 1996). Thus, restoring historic conditions, including disturbance regimes, is important in maintaining or restoring the integrity of native fish assemblages (Minckley and Meffe 1987; Poff et al. 1997; Moyle et al. 1998). Introduction of non-native fish species has been widespread and has resulted in the homogenization of fish faunas across the United States (Rahel 2000; 2002). In the past, most fish introductions involved intentional release of species useful to humans such as game or aquaculture species. At the basin and landscape scale, these introductions typically increase overall fish species richness and do not appear to have caused the extirpation of many native species (Moyle and Light 1996; Gido and Brown 1999). But at the scale of individual water bodies or streams, introduced species, especially piscivores, can extirpate native species (Findlay et al. 2000). In the Rocky Mountain Region, a primary cause of the decline of native cutthroat trout populations has been competition or hybridization with introduced trout species (Fig. 3.10) (Young 1995).

A Hierarchy of Factors that Influence Fish Assemblages

The factors that influence fish assemblages can be viewed as a hierarchy of natural processes and anthropogenic alterations. At the largest spatial scale (e.g., basin scale), the continental species pool is filtered by natural processes, such as glaciation, mountain uplifts, and zoogeographic barriers, to produce the regional species pool. Anthropogenic factors that determine the regional species pool include introduction of exotic species (Rahel 2000) or creation of transbasin water diversions that provide routes for species invasions (Mills et al. 1994). From this regional pool, the distribution of individual species across the landscape (4th level and 6th level HUBs) is often determined by large-scale habitat gradients related to climate, e.g., temperature and precipitation regimes and landforms and surficial geology that determine the general types of aquatic habitats present in the region.

Anthropogenic alterations important at this scale include reservoir construction, the creation of migration barriers, and fish stocking. Within the distribution range of species, local habitat factors interact with biotic processes such as competition, predation or disease to determine species abundance at the reach/site scale (Tonn et al. 1990).

Information Needs for the Different Ecological Scales

Basin Scale

Information needed to understand the fish resources at the basin scale include the following:

(1) Identification of the zoogeographic history.

In many cases, historical zoogeographic factors have been a major factor in determining patterns of fish species richness, endemism and taxonomic composition across basins (Abell et al. 2000). Zoogeographic factors include historical events that operate over large spatial scales such as barriers to dispersal (basin boundaries), the location of glacial refuges and postglacial colonization routes and landform changes that influence drainage patterns and connectivity (mountain uplifting, stream capture) (Matthews 1998). For example, eastern and western North America have had independent faunal histories since the uplift of the Rocky Mountains (Gilbert 1976) and thus, fish assemblages east and west of the continental divide within a single national forest can be distinct. Therefore it is important to understand zoogeographic history when assessing the current status of fish assemblages.

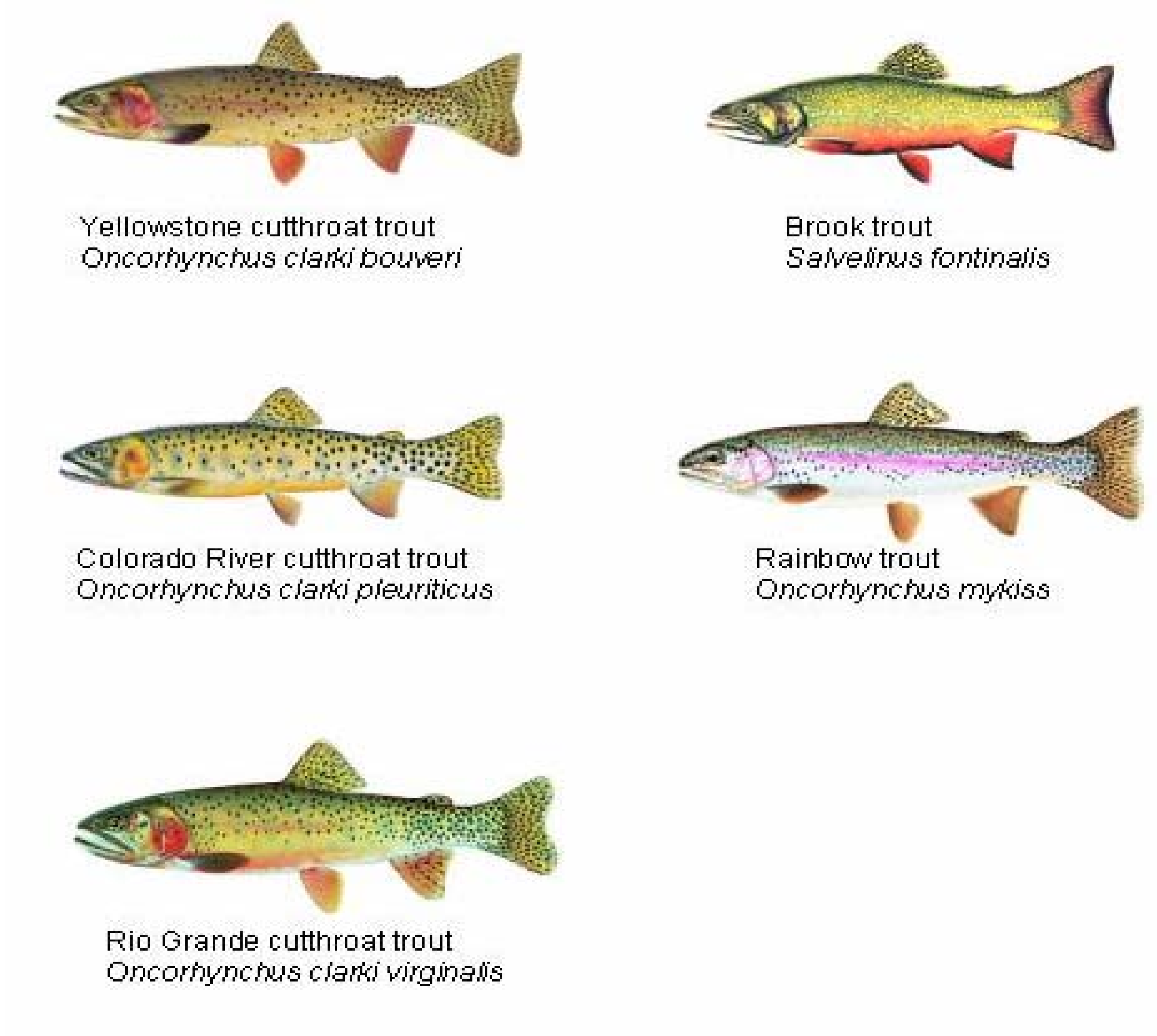


Figure 3.10. Important gamefish species in the Rocky Mountain region. The subspecies of cutthroat trout are native to the region but their populations have declined due to competition with introduced brook trout and/or hybridization with introduced rainbow trout. Trout prints are copyrighted by Joseph R. Tomelleri and used with permission.

Consideration of zoogeographic history has played a major role in efforts to delineate freshwater ecoregions, e.g., collections of basins that share similar species richness, levels of endemism and dominant taxa. The aquatic ecoregions for North America have been characterized by Maxwell et al. (1995). The patterns of fish species richness and endemism for these ecoregions have been characterized by Abell et al. (2000). Information on dominant fish taxa within major basins can be found in Hocutt and Wiley (1986) and Mayden (1992) as well as state fish books (e.g., Baxter and Stone 1995).

Landscape Scale

Information needed for fish at the landscape scale includes the following:

(1) Make a list of the fish species and their status as native or introduced.
(2) Understand the climate, surficial geology, and the flow regime.

A list of fish species and their status as native or introduced provides a basic inventory of fishery resources for each 4th level HUB on the Forest. At this relatively large spatial scale, zoogeographic factors may continue to exert a big influence on fish distribution patterns. Forests that straddle major basin divides can have different species assemblages in adjacent 4th level HUBs that flow in different directions. For example, streams on the Routt-Medicine Bow National Forest that flow into the Colorado River basin naturally have species such as Colorado River cutthroat trout and mottled sculpin that are not found in nearby drainages with similar habitat that flow into the Missouri River basin (Baxter and Stone 1995). Assessing species conservation status at this scale will identify taxa that are jeopardized over a fairly large extent of their historic range and which will likely need attention if they are to remain part of the Forest's biota.

Several key abiotic factors are likely to influence fish assemblages across 4th level HUB boundaries. These include climate and surficial geology.

Climate affects thermal conditions in aquatic systems, which then determine the type of fish species likely to occur. For example, the coldwater fish guild is not likely to persist in the Rocky Mountain Region in areas where mean July air temperatures exceed 22°C (Keleher and Rahel 1996). Various species of trout may have distributions defined by thermal envelopes. For example, the geographic distribution of brown trout in eastern Wyoming was limited to a thermal envelope defined by mean July air temperatures of 19-22°C with higher elevations dominated by brook trout and lower elevations dominated by minnows and suckers (Rahel and Nibbelink 1999). Because of increasing thermal conditions, streams in the Rocky Mountains show a characteristic transition from dominance by various species of trout in headwaters to dominance by minnows and suckers at lower elevations (Rahel and Hubert 1991). Climate also affects hydrological patterns such as the timing and magnitude of flood events that, in turn, influence the biology of stream systems (Poff and Ward 1990). For example, the establishment of rainbow trout outside of their native range has been most successful in areas that experience winter flooding and summer low flows that mimic conditions within their native range (Fausch et al. 2001).

Surficial geology can determine coarse scale patterns of water fertility and susceptibility to acid precipitation. The abundance of carbonate rocks influences stream alkalinity, a measure of nutrient content often correlated with the abundance of aquatic organisms (Krueger and Waters 1983; Kwak and Waters 1997). The abundance of carbonate rocks also determines the sensitivity of aquatic systems to cultural acidification because carbonate and bicarbonate ions help buffer against the effects of elevated hydrogen ions in acid precipitation (Haines 1981). Surficial geology also can influence stream characteristics related to fish habitat such as sedimentation patterns and pool formation. Nelson et al. (1992) found that cattle grazing appeared less detrimental to fish populations in a sedimentary district (where weathering produced riparian soils dominated by gravel) compared with a detrital district (where weathering produced riparian soils dominated by silts that eroded into the stream with cattle trampling). Modde et al. (1991) observed that surficial geology contributed to differences in stream habitat among land-type associations in the Black Hills National Forest of South Dakota and Wyoming. In particular, streams within the limestone canyon land-type had greater pool development and higher brown trout biomass than streams within the other land-type associations.

Anthropogenic processes likely to influence fish distribution patterns at the landscape scale (4th level HUB) include changes in the type or connectivity of aquatic systems caused by reservoirs, water diversion structures, or alteration of streamflow regimes. Reservoirs create a new habitat type (warm water lentic environment) that was historically rare in the Rocky Mountain-Great Plains region (Moyle and Light 1996). Furthermore, western reservoirs often are populated by nonnative fish species such as percids (walleye, perch), esocids (northern pike) and centrarchids (black bass) that can have detrimental effects on native species (Carlson and Muth 1989; Rahel 2000). The effects of these non-native species can extend upstream into riverine habitats (Pringle 1997). Reservoir dams can block fish migrations and lead to extirpation of fish populations upstream or reduced genetic exchange among populations (Winston et al. 1991). And even relatively low-head dams can be barriers to movements of some fish species (Porto et al. 1999).

Another important anthropogenic disturbance operating at this scale is altered flow regimes. Flow-regime alterations can result in reductions in peak spring flows and/or augmentation of low summer/autumn flows (Fausch and Bestgen 1997). Reductions of spring floods and depletion of sediment inputs can cause the stream channel to downcut with the result that a braided channel with many backwater areas is replaced by a single, deep channel. Small-bodied fish species associated with side channels and backwater areas are reduced while large-bodied, riverine species are favored (Patton and Hubert 1993). Interestingly, flow enhancements also can be harmful to native species. Exotic species that are not as well adapted as native fishes to harsh, intermittent stream environments may be favored when summer flow enhancement prevents high temperature and low oxygen conditions (Minckley and Meffe 1987). To mitigate the effects of flow alterations, ecologists are increasingly urging managers to consider restoring natural flow regimes as a way to preserve natural habitats and native species in rivers (Poff et al. 1997).

Management Scale

Information needed at the management scale for fish resources includes the following:

(1) Understand the basin geomorphology, natural fish migration barriers, and the fire history of the area.
(2) Understand the anthropogenic influences e.g., reservoirs, water diversion structures, timber harvest, livestock grazing, road density and any introduced fish disease in the area.

At the management scale, a 6th level HUB may encompass one or more of the climate zones, hydrologic regimes, major vegetation zones, and surficial geology categories discussed above for the landscape scale (4th level HUB). As discussed earlier, these are drivers of biological processes and thus will continue to affect fish distribution patterns at the management scale (6th level HUB). In many cases, a 6th level HUB may be partitioned longitudinally along these major gradients by overlaying maps generated at the landscape scale. The resultant overlays will allow identification of areas having similar large-scale determinants of community structure (e.g., similar thermal conditions, hydrologic regimes, vegetation and water chemistry).

Other natural drivers likely to be important at the management scale are basin geomorphology, natural fish migration barriers, and fires. For example, the distribution of bull trout in the upper Boise River system in Idaho was related to watershed size, with larger watersheds more likely to contain bull trout than smaller ones (Rieman and McIntyre 1995). Natural barriers to fish movements were a historically important feature in determining fish distributions among tributaries within 6th level HUB watersheds. The upper elevations of many Rocky Mountain watersheds were naturally fishless because fish could not pass above waterfalls or high gradient reaches (Franke 1996). Bahls (1992) estimated that only 5% of the 16,000 high mountain lakes in the western United States naturally contained fish. Today, about 60% of these lakes contain trout as a result of extensive stocking efforts and the majority of these lakes require continued stocking to maintain fish populations. Migration barriers continue to be a major influence on fish distributions in high elevation streams. Kruse et al. (1997) noted that Yellowstone cutthroat trout in the Absaroka Mountains of Wyoming were absent above natural barriers consisting of waterfalls at least 1.5 m high or reaches with channel slope greater than 10%.

Forest fires can have important effects on aquatic ecosystems in the western United States (Minshall et al. 1997; Gresswell 1999). Most wildfires burn only a small area (<1 hectare) but larger fires that burn a significant portion of a watershed (10^4 to 10^6 ha) occur at regular intervals in the western United States. The consequences of large fires for aquatic systems can be considered on three time scales; short-time effects during or immediately after the fire, midterm effects occurring from 1-5 years post-fire, and long-term effects lasting 10s or 100s of years after the fire (Minshall et al. 1997). Short-term effects include mortality of fish due to elevated water temperatures or direct inputs of ash into the stream but such mortality is localized and defaunated patches are usually quickly recolonized by nearby populations (Minshall and Brock 1991). Midterm consequences include fish and invertebrate mortalities from massive inputs of sediment and ash during highflow events that may occur several years after the fire (Bozek and Young 1991), pulses of nutrients that may stimulate stream productivity (Bayley et al. 1992), and increased solar radiation if the riparian vegetation canopy has been lost (Gresswell 1999). The effects of increased solar radiation on aquatic biota depends on the pre-burn thermal conditions as salmonids may benefit from warming of extremely cold streams but may suffer if streams were already close to the thermal limits of cold water biota. There may also be an increased input of large woody debris for several years as fire-killed trees eventually fall into streams (Minshall et al. 1997).

Long-term consequences include increased nutrient and sediment inputs until soils and vegetation recover to pre-burn conditions and a dearth of large woody debris inputs until large trees regrow (Minshall et al. 1997). Litter inputs increase as deciduous vegetation colonizes burned areas and may exceed pre-fire levels but gradually declines as succession leads to domination by conifers. The negative consequences of fire to fishes are generally short-lived and localized providing there are sources of fish to recolonize burned areas. An exception involves isolated populations that may be extirpated. Rinne (1996) reported that one of the few remaining populations of the endangered Gila trout (*O. gilae)* was extirpated following postfire flood events. This is a potentially serious problem in the Rocky Mountain Region because many of the remaining populations of native cutthroat trout and bull trout are in small, isolated tributaries where colonization from other populations is unlikely (Rieman and McIntyre 1995; Young 1995). The effects of fires on lake biota have not been studied extensively. In general, forest fires appear to have little effect on water quality or productivity in lakes. This is probably because water renewal times minimize the consequences of a few years of increased nutrient inputs and because much of the water entering lakes does so as groundwater (Gresswell 1999).

Anthropogenic processes that influence fish distribution patterns at this scale include changes in the type or connectivity of aquatic systems caused by reservoirs, water diversion structures, or alterations of streamflow regimes as noted for the basin scale. Additional anthropogenic processes that could be important at the landscape scale include the extent of timber harvest, livestock grazing, road density, and introduced fish diseases (e.g., whirling disease). There is an extensive literature on the effects of timber harvest on fish and fish habitat (Chamberlin et al. 1991). Many of the effects are negative, including increased sediment delivery to streams, altered streamflows (e.g., higher peak flows during spring runoff), loss of large woody debris inputs, and warming of streams. Interestingly, sometimes the effects of timber harvest can be beneficial such as when warming enhances fish production in cold habitats (Holtby 1988) or increased light levels following canopy removal increase the foraging efficiency and growth of trout (Wilzbach et al. 1986).

Improperly managed livestock grazing is generally considered to be harmful to fish populations because trampling of streambanks causes increased sediment and loss of fish cover in the form of overhanging vegetation and undercut banks (Platts 1991). Bank damage by cattle grazing was a significant (and negative) influence on trout biomass in a regression model relating trout biomass to various habitat features of high-elevation streams in Arizona (Clarkson and Wilson 1995). This was important because bank damage by cattle was the only variable solely influenced by land management practices. The other variables (stream width, station elevation, channel type, and riparian area width) were mainly under geomorphic control and thus would not be responsive to land management practices. In most cases, grazing impacts are studied at the stream reach level and focused within the riparian zone. Isaak and Hubert (2001), however, present evidence that livestock impacts can operate at the drainage basin level. Using path analysis, they showed that livestock accelerate water runoff by increasing soil compaction across the drainage. Accelerated runoff, in turn, causes reduced stream baseflows. Thus, grazing by domestic animals appears to decrease the volume of stream habitat during a period (late summer/autumn) that is critical for stream biota.

Road density can negatively influence fish assemblages in four ways. First, road construction can alter channel morphology if roads are placed adjacent to the stream as often occurs in mountainous regions or if flow restrictions at culverts increase the scouring power of the stream. Such channel alterations can result in a loss of undercut stream banks and riparian vegetation. Second, unpaved roads are a source of sediments during rainfall or snowmelt events and contribute airborne dust particles from passing vehicles during dry periods (Eaglin and Hubert 1993). This increased sedimentation is generally viewed as harmful because it reduces reproduction in fishes such as trout and suckers that deposit their eggs in gravel substrates. Third, roads facilitate human access to streams and lakes and this can greatly increase angling exploitation of fish populations (Gunn and Sein 2000). Fourth, road culverts can serve as barriers to fish movement. This can occur when water velocities exceed fish swimming abilities or when the culverts are placed above the grade of a stream such that fish cannot jump high enough to enter the culvert (Belford and Gould 1989). Although blockage of fish movement is generally considered harmful, it can be beneficial when road culverts prevent non-native species from migrating upstream and harming native species. This is particularly true for cutthroat trout in the western United States where road crossings have been intentionally designed to prevent upstream colonization by brook trout or rainbow trout (Thompson and Rahel 1998).

Reach/Site Scale

Information needed at the reach/site scale for fish include the following:

(1) Stream size, channel slope, habitat types, condition of the riparian zone, and the substrate composition.

The large-scale factors discussed above determine the species likely to be present within a 6th level HUB drainage and set upper bounds to species abundance. However, the abundance of fish is further determined by habitat factors operating at the reach/site scale (Bjornn and Reiser 1991; Orth and White 1999) and fish populations often respond to habitat improvements done at this scale (Reeves et al. 1991; Binns 1999). A large number of reach/site level habitat factors have been associated with fish abundance and identifying causative factors is difficult because of correlations among habitat features (Fausch et al. 1988; Isaak and Hubert 2000). For example, Hubert and Kozel (1993) reported that stream discharge was highly correlated (r^2>50%) with mean bank-full width, mean wetted width, mean water depth, and the number of deep pools for mountain streams in Wyoming. There is little agreement as to which specific habitat features are most important in determining fish abundance (Kozel and Hubert 1989). And such agreement is unlikely because limiting habitat features can differ among drainage basins (Bowlby and Roff 1986; Hubert and Rahel 1989; Leftwich et al. 1997; Porter et al. 2000). In general, however, features related to stream size, channel slope, relative abundance of habitat types (e.g., runs, pools, riffles), riparian condition, substrate condition, and the abundance of cover are important determinants of fish abundance at the reach/site scale.

Stream size is an important determinant of fish assemblage characteristics. Larger streams typically have more species and larger fish than smaller streams and this has been attributed to an increase in living space and habitat complexity as stream size increases (Schlosser 1987; Rahel and Hubert 1991; Larscheid and Hubert 1992). Stream size can also influence the types of species present. In the central Rocky Mountain Region, brook trout often dominate smaller streams whereas brown trout and rainbow trout dominate larger streams (Rahel and Nibbelink 1999).

Channel slope is important because it influences the types of habitat units present (e.g., riffles, pools, and cascades) and substrate characteristics. High gradient reaches are dominated by riffles or cascade habitats whereas runs and pools dominate low gradient reaches. Channel slope has been related to the presence/absence (Kruse et al. 1997) and standing stock (Chisholm and Hubert 1986) of trout in streams.

The relative abundance of habitat types such as runs, pools, and riffles influences the species composition and size-classes of fish present in a reach. Riffles provide habitat for habitat specialists such as longnose dace and for the young of many species that are excluded from pools by larger fish (Harvey 1991). Pools provide habitat for fish that are not strong swimmers (e.g., sunfish) and provide energetically favorable habitats for other species such as trout (Rosenfeld and Boss 2001). In general, the biomass of fish in pools is higher than the biomass in nearby riffles (Hankin and Reeves 1988; Herger et al. 1996) and management manipulations that increase the amount of pool habitat often increase fish abundance in streams (Reeves et al. 1991; Riley and Fausch 1995; Binns 1999).

The condition of the riparian zone influences fish community attributes in both cold water and warm water streams (Wang et al. 1997; Covington and Hubert 2000). Healthy, vegetated riparian zones provide cover for fish in the form of undercut banks or overhanging vegetation

(Wesche et al. 1987) and reduce sediment inputs to a stream (Platts 1991). Stabilization of stream banks by the roots of riparian vegetation causes downcutting of the channel, resulting in deeper pools and riffles (Covington and Hubert 2000). Finally, riparian vegetation moderates water temperatures by shading the channel and increases allochthonous energy in the form of leaf fall and terrestrial insects (Hubert and Rhodes 1989).

Substrate composition is an important component of fish habitat. Pocket pools created by rocks in riffle areas provide habitat for small fish that would otherwise be unable to occupy high velocity areas (Bozek and Rahel 1991; Rosenfeld and Boss 2001). Interstitial spaces amongst cobble and boulders shield fish from high current velocities and provide protection from predators. Such hiding places appear to be especially important for fish in winter when cold water temperatures reduce swimming performance and make fish vulnerable to endothermic predators (Griffith and Smith 1993). Land-use practices that contribute fine sediments to streams can eliminate interstitial habitat and reduce over-winter survival of fish (Cunjak 1996). Boulders provide a current refuge for larger fish and create energetically favorable feeding sites. Finally, many fish, including most trout species, deposit their eggs within gravel substrates and experience reduced reproductive success when fine sediments are abundant (Waters 1995).

For stream fishes, cover typically involves habitat features that provide velocity refuge, visual isolation from competitors, or a refuge from predators (Bjornn and Reiser 1991; Fausch 1993). Velocity refuge can be provided by boulders that allow fish to hold low-velocity positions adjacent to fast water thus maximizing their energy intake from drifting invertebrates while minimizing the energetic costs of swimming. Visual isolation provided by boulders or woody debris reduces intra- and interspecific aggression and thus increases the density of fish that can occupy a given area. Refuge from predators is provided by deep water, surface turbulence, aquatic vegetation, debris jams, or overhanging riparian vegetation (Wesche et al. 1987; Hubert et al. 1996). Habitat manipulations that involve placement of large boulders or woody debris in streams can increase fish abundance substantially (Shuler et al. 1994; Binns 1999).

Anthropogenic related factors that influence fish assemblages at the reach/site scale include degradation of streambanks due to livestock trampling, removal of riparian vegetation by timber harvest, and introduction of fine sediments due to roads. The effects of these factors were discussed earlier (see management scale). Angler harvest can have a profound effect on fish populations by reducing the numbers of large gamefish and causing shifts to species that are less vulnerable or desirable to anglers (Anderson and Nehring 1984). Sometimes, harvest restrictions or fishery closures are necessary to protect species that are highly vulnerable to angling (Schmetterling and Long 1999). For example, the abundance and average body size of west-slope cutthroat trout, a species of conservation concern, increased in several populations in Montana following angling restrictions (McIntyre and Rieman 1995).

CHAPTER 4
ECOLOGICAL DRIVER CONCEPT

The Importance of Ecological Drivers in Determining Aquatic, Riparian, and Wetland Resources

Ecological drivers are environmental factors that exert a major influence on aquatic, riparian, and wetland ecosystems and ultimately on the fitness of individuals and species population size. These drivers can be considered as comprising the physico-chemical "template" of an ecosystem (Poff and Ward 1990). And the dominant expression of these drivers at a particular spatial scale influences the relative success of species and thus community composition at that scale (Poff 1997). Thus, characterizing the expression of drivers for particular spatial units (e.g., 6th level HUBs) across the Forest provides a basis for expectation of ecological condition within those units. Similarly, where drivers are modified by human activity, an altered template creates conditions that favor an altered ecological community. Therefore, identifying the major ecological drivers is an appropriate place to begin an ecosystem-level assessment because of the overwhelming influence of habitat conditions on the distribution and functioning of aquatic, riparian, and wetland resources across a region.

Identifying Major Ecological Drivers

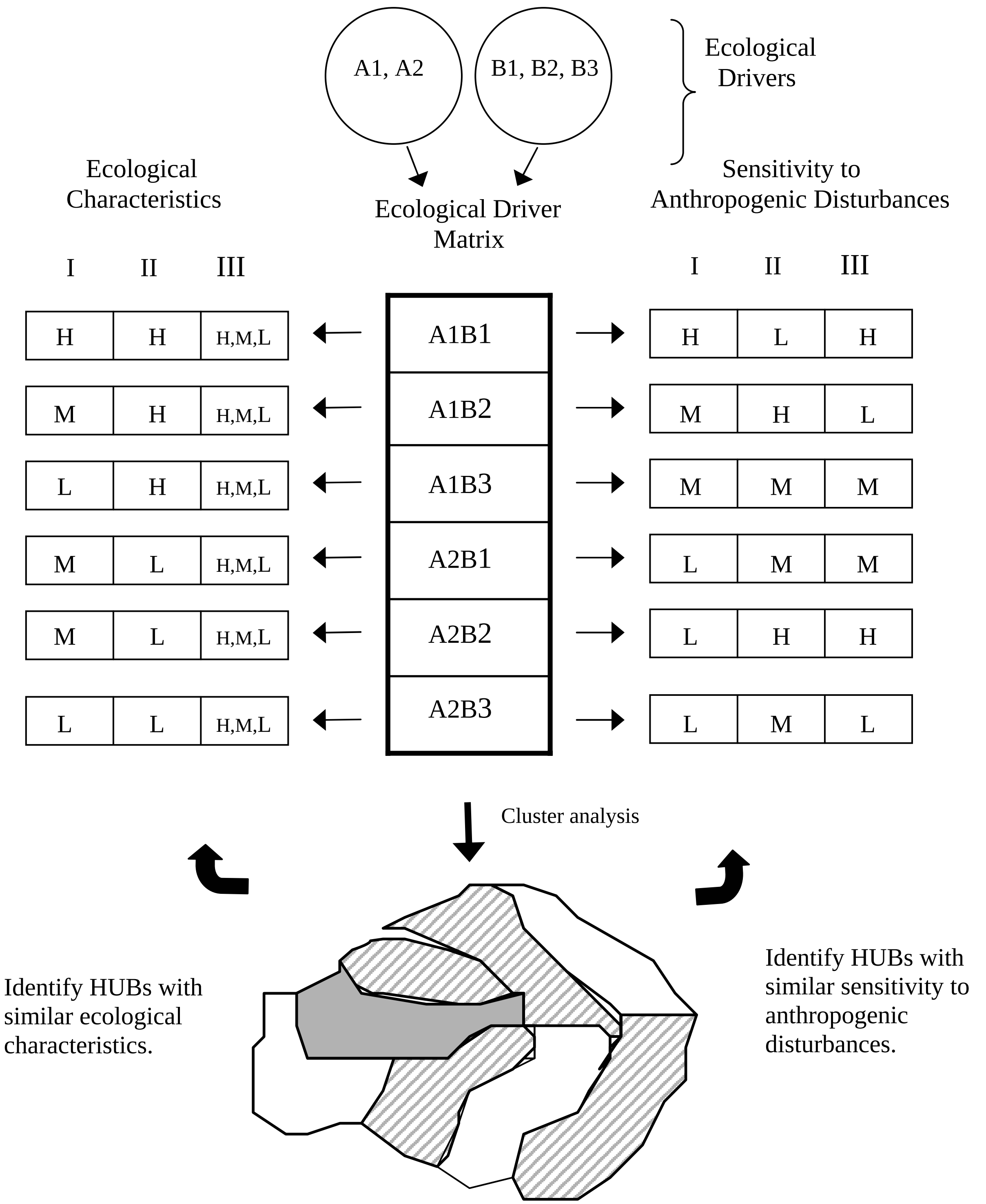
Identifying the major ecological drivers important for determining aquatic, riparian, and wetland resources within a region forms the basis for the ecosystem assessment protocol described in this document. There is an extensive scientific literature that describes the influence of various abiotic and anthropogenic factors on the structure and function of aquatic, riparian, and wetland ecosystems (see reviews in *Chapter 3: Ecological Characteristics of Aquatic, Riparian and Wetland Ecosystems*). From this literature, a team of hydrologists, ecologists, and biologists familiar with the region should be able to identify a set of ecological drivers that determine the spatial distribution and levels of productivity for aquatic, riparian, and wetland ecosystems in the management area of interest.

To help identify key ecological drivers and to explore interactions among driver combinations, it may be insightful to develop an ecological driver matrix such as the one shown in Figure 4.1. In such a matrix, rows are the ecological driver combinations occurring in the study area and columns are the ecological characteristics of interest to resource managers such as the abundance of fish or the occurrence of various wetland types. Entries in each cell reflect the ecological condition expected for a particular driver combination in the absence of anthropogenic disturbances. Often the expected conditions can be stated only in qualitative terms, such as high, medium, or low categories, but if quantitative data are available they can be portrayed as well.

In Figure 4.1 there are two ecological drivers labeled A and B. Driver A exists in two states (A1, A2) and driver B exists in three states (B1, B2, B3). This results in 6 (2x3) possible driver combinations. There are three ecological characteristics of interest (I through III) and each is described as being at a high (H), medium (M), or low (L) level. Also, there are three types of anthropogenic disturbances of interest (I through III) and the sensitivity of each driver combination to a given disturbance is described as high (H), medium (M), or low (L).

The matrix can be used in several ways. One can ask what ecological characteristics are likely to occur for a particular combination of drivers. For example, combination A1B1 results in high levels for ecological characteristics I and II whereas A2B3 results in a low level for these characteristics. Alternately, one can ask what driver combinations produce a particular ecological condition. In Figure 4.1, ecological characteristic I exists at a low level whenever

Figure 4.1. Flow chart depicting the process of identifying driver combinations that are important in determining ecological characteristics and sensitivity of watersheds to disturbance.



Schematic of a 4th level HUB watershed showing 6th level HUBs with similar driver combinations.

driver B exists in the B3 state. For example, if ecological characteristic I was trout abundance and driver B was thermal regime with B3 representing warm conditions, then trout abundance would always be low regardless of the status of the other drivers because trout cannot survive in warm water conditions. Figure 4.1 also indicates that ecological characteristic II is sensitive only to the level of driver A1 and that characteristic III is insensitive to the drivers because it can exist at a high, moderate, or low level regardless of the combinations of drivers A and B.

The ecological driver matrix has several management applications. The driver categories (six in this example) could be mapped across the management area using a technique such as cluster analysis to identify watersheds or HUBs with a similar combination of driver states as depicted in Figure 4.1. One could then go to a particular location and have an assessment of what baseline ecological characteristics should be. This information might be especially useful if an area has been degraded and you need an indication of the ecological potential of the area if it was to be rehabilitated. A map of driver combinations also would indicate where areas of similar ecological potential occur even though such areas might be widely dispersed throughout the region.

Another management application involves identifying which driver combinations are needed to support certain ecological conditions. For example, in Figure 4.1, ecological characteristic I exists at a high level only for one of the six driver combinations (A1B1). If such a state was important in management goals, then protecting areas with this driver combination becomes a high priority. For example, A1B1 might be the only driver combination that produces abundant wetlands at high elevations that are habitat for several endangered amphibian species.

The ecological driver matrix also can help identify gaps in our understanding of which drivers influence ecological conditions. When the driver combinations were applied to ecological characteristic III in Figure 4.1, there was no pattern between the high, medium, or low levels for any driver combination. This indicates that these drivers do not influence this characteristic. Managers would then need to look for other drivers influencing this ecological characteristic.

Driver Combinations for Addressing Aquatic, Riparian, and Wetland Resources

The flowchart in Figure 4.2 is the driver concept used in the Bighorn National Forest assessment and should be used to analyze natural resources in other mountain environments in Region 2. According to the flowchart in Figure 4.2 the first drivers to be assessed in a mountainous environment are geology (calcareous vs. non-calcareous) and climate (snowmelt, rain and snow, or rain). The second tier of drivers is glaciation, stream gradient, and temperature.

The information related to these two tiers of drivers are then used to determine the resource values for (1) wetland and riparian distribution and extent; (2) physico-chemical conditions; and (3) aquatic productivity and community characteristics. For example, in the Bighorn National Forest assessment of aquatic production the following driver combinations were analyzed: climate, stream gradient, and temperature. Whereas, the physico-chemical conditions of the Forest were determined by evaluating the geology, climate, and stream gradient driver data. Each of these analyses will be important in determining the characteristic(s) for that particular resource value. This information will be valuable in identifying similar 6th level HUBs across the landscape and not just within a National Forest boundary. By accomplishing this at a broader scale than within administrative boundaries, we should be able to better understand the range of potential conditions at the reach/site scale, to identify the conditions least and most influenced by anthropogenic resources, and to be more consistent and defensible when addressing planning and project level analysis.

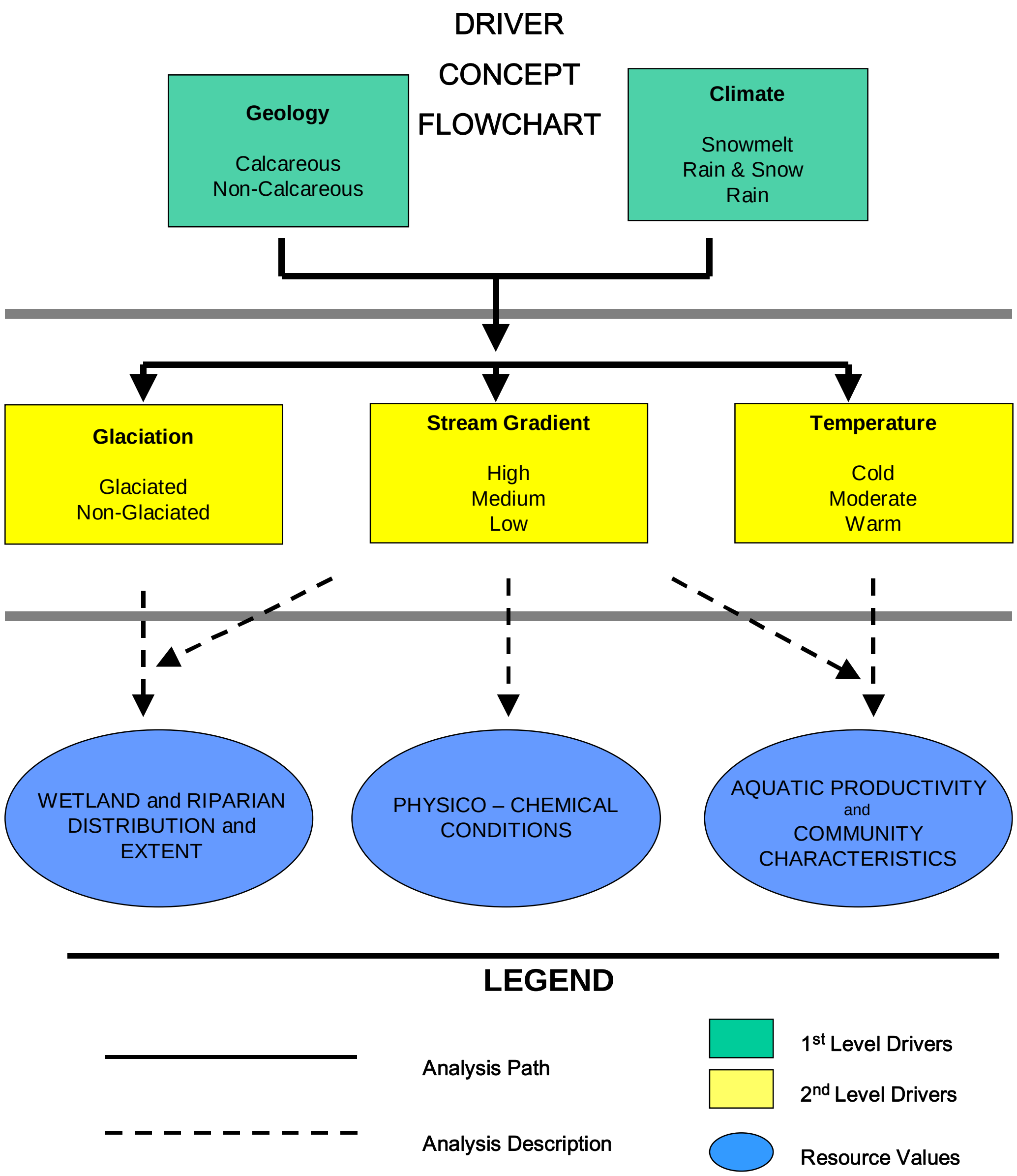


Figure 4.2. Flowchart of the hierarchical nature of the aquatic, riparian, and wetland assessment protocol for mountain environments.

An Approach for Analyzing and Mapping Driver Combinations

Drivers are chosen based upon their known or hypothesized importance for controlling hydrologic, geomorphic, and ecological processes within watersheds. Hydrologic unit boundaries (HUBs) with a similar percentage of their area with the same driver combinations should support similar watershed characteristics and function similarly. Thus, the landscape scale analysis of 6th level HUBs based upon the area occupied by each driver combination provides a means of subdividing large regions based upon their ecological potential and sensitivity to certain anthropogenic disturbances. As an example, the following section presents an approach and gives an example for analyzing the influence of three drivers on wetland and riparian ecosystems in the Bighorn National Forest in northern Wyoming. We present a multivariate statistical classification and ordination of HUBs and analyze wetland types and areas within these HUBs.

Description of the Ecological Driver Cluster Analysis

Ecological drivers are components of the land, water and air that are the primary factors responsible for the way that aquatic, riparian, and wetland resources appear and function in the absence of Euro-American inhabitants. For riparian areas, stream gradient, precipitation regime, and lithology were considered to be the dominant ecological drivers. For wetlands, the presence or absence of Pleistocene glaciation, precipitation regime, and lithology were considered to be dominant ecological drivers (Table 4.1).

Table 4.1. Driver definitions used for the Bighorn National Forest aquatic, riparian, and wetland assessment.

Assessment	Driver	Description	Abbreviation
Riparian, Wetland, and Aquatic	Geology	Calcareous	**Ca**
		Non-Calcareous	**Cn**
Wetland	Glaciation	Glaciated	**Qa**
		Unglaciated	**Qn**
Riparian, Wetland, and Aquatic	Climate	Snowmelt	**Ps**
		Rain and Snow	**Prs**
		Rain	**Pr**
Riparian and Aquatic	Gradient	Low	**Gl**
		Moderate	**Gm**
		High	**Gh**

In order to simplify the complex nature of the Bighorn landscape, an agglomerative cluster analysis was performed to identify HUBs with similar distributions of ecological drivers (Fig. 4.3). For the landscape and management scale, the percent coverage of each driver was calculated using GIS for each 6th level HUB (Table 4.2). A Sorenson method cluster analysis was performed for the HUBs comprising each scale using a group average linkage method. The analysis produced a dendrogram, which was used to define the similarity threshold that would identify the watershed groupings (Fig. 4.4). The cluster groupings identified in the dendrogram were then joined to the watershed coverage of the pertinent scale, and mapped using the ARWA cartographic standards (Fig. 4.5).

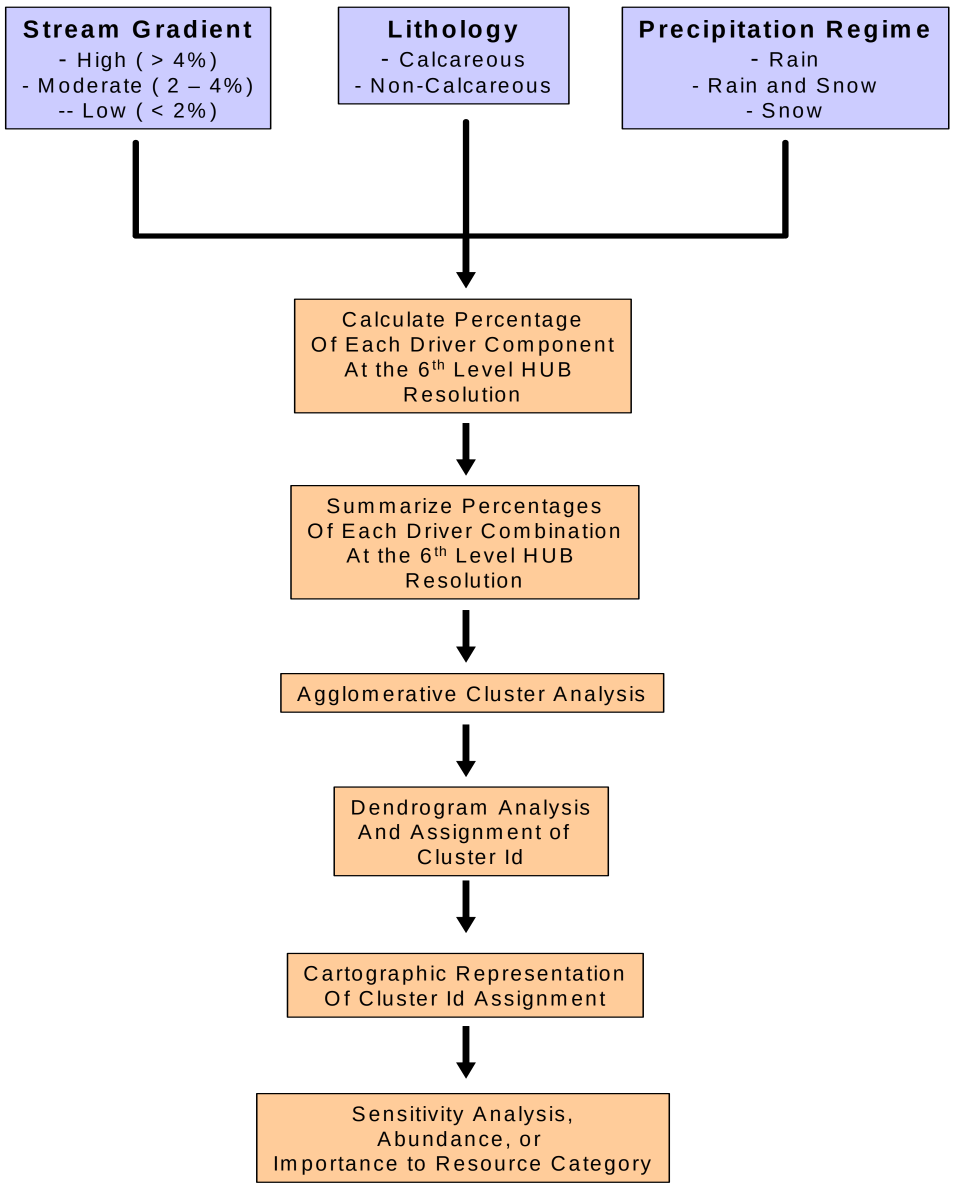


Figure 4.3. Conceptual model of the ecological driver cluster analysis for riparian ecosystems.

Table 4.2. Percent area encompassed by individual ecological drivers for the management scale aquatic and riparian ecosystem assessment of 74 6th level HUBS intersecting the Bighorn National Forest.

	Percent Area or Length Encompassed by a Specific Ecological Driver							
	Geology		Climate (precipitation)			Stream gradient		
HUB	Ca	Cn	Pr	Prs	Ps	Gh	Gm	Gl
A	11.37	**88.63**	0.07	21.22	**78.71**	**57.16**	32.33	10.52
B	**52.57**	47.43	0.46	**46.89**	52.65	**44.68**	34.40	20.92
C	9.86	**90.14**	17.43	**66.09**	16.49	**50.12**	20.09	29.78
D	**58.84**	41.16	8.95	21.18	**69.87**	**79.76**	13.20	7.04
E	**77.13**	22.87	31.34	**53.94**	14.72	**62.00**	18.23	19.78
F	16.79	**83.21**	**76.61**	20.61	2.78	31.90	28.38	**39.72**

***Ca** – calcareous geology, **Cn** - non-calcareous geology; **Pr** - rain driven hydrology, **Prs** – rain-and snow driven hydrology, **Ps** - snowmelt driven hydrology, **Gh** - high gradient stream reaches, **Gm** – moderate gradient stream reaches, **Gl** - low gradient stream reaches.*

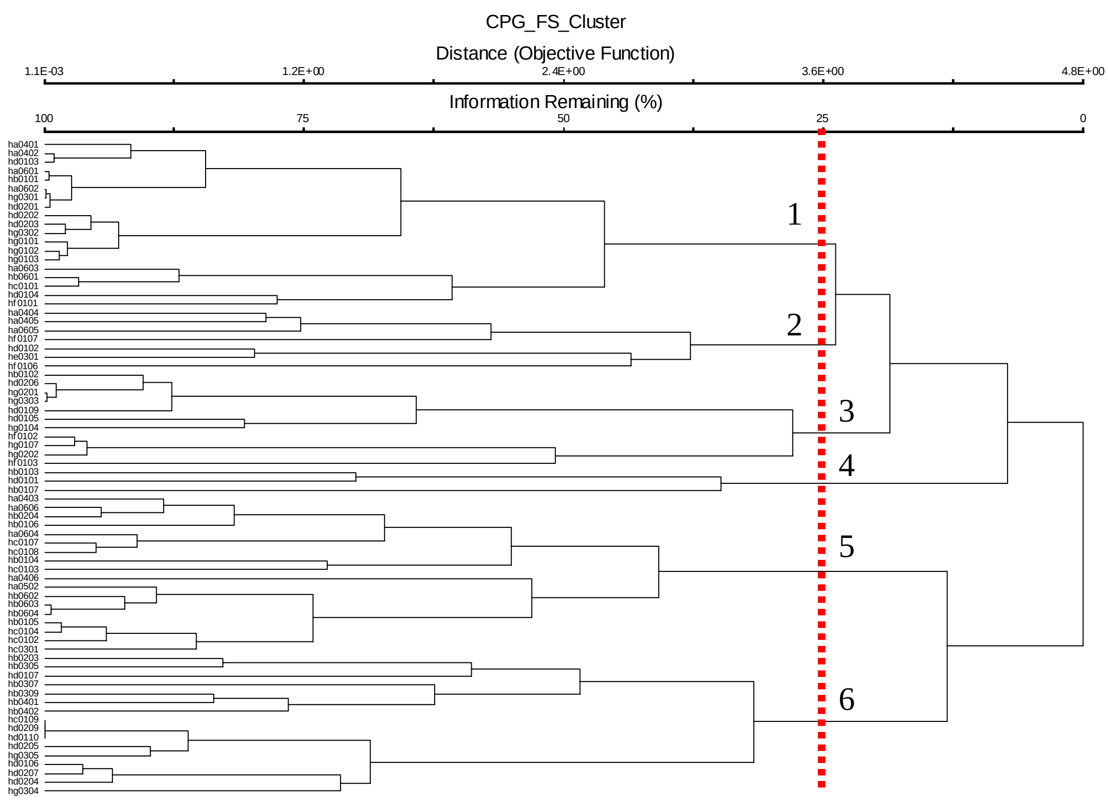


Figure 4.4. Management scale agglomerative cluster analysis of riparian and aquatic ecosystems using the 74 6th level HUBs that intersect the Bighorn National Forest.

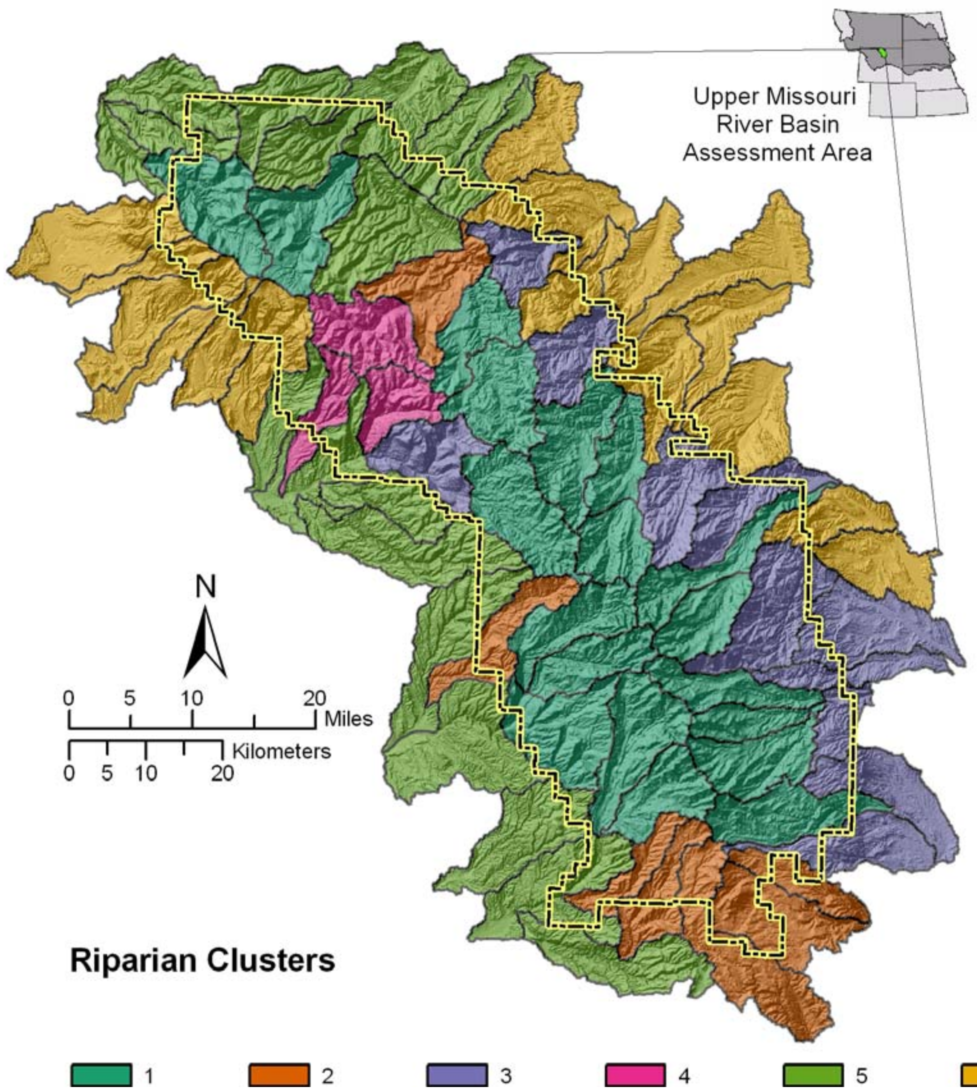


Figure 4.5. Distribution of six cluster groups for riparian and aquatic ecosystems based on management scale analysis of ecological drivers for 74 6th level HUBs intersecting the Bighorn National Forest.

<u>An Example of the Analytical Methods Using Wetland and Riparian Data</u>

The three drivers chosen for the analysis of wetlands in the Bighorn National Forest were (1) geology, (2) glaciation, and (3) climate regime. These drivers were chosen because they exert the greatest control over water chemistry, landscape heterogeneity and gradient, and characteristics of the hydrologic regime in the study area. The proportion of each 6th level HUB's area having each of these drivers was quantified using data layers for bedrock geology, surficial geology, and precipitation regime (based upon elevation). Other modifiers, such as stream or valley gradient could also be used in this analysis.

Three steps can be utilized for analyzing HUBs. First we classify the percentage of each HUB's area in each driver combination. Second, we do an indirect ordination of the HUBs to identify which drivers are controlling the classification structure. Third, we create a HUB classification to analyze the distribution of wetland and riparian areas in the Bighorn National Forest. Two wetland data sets were utilized: (1) a riparian classification and mapping of the Bighorn National Forest (Girard et al. 1997), and (2) the U.S. Department of Interior, National Wetlands Inventory (NWI) data (Cowardin et al. 1979). The NWI data are incomplete, and we used only HUBs with complete NWI data.

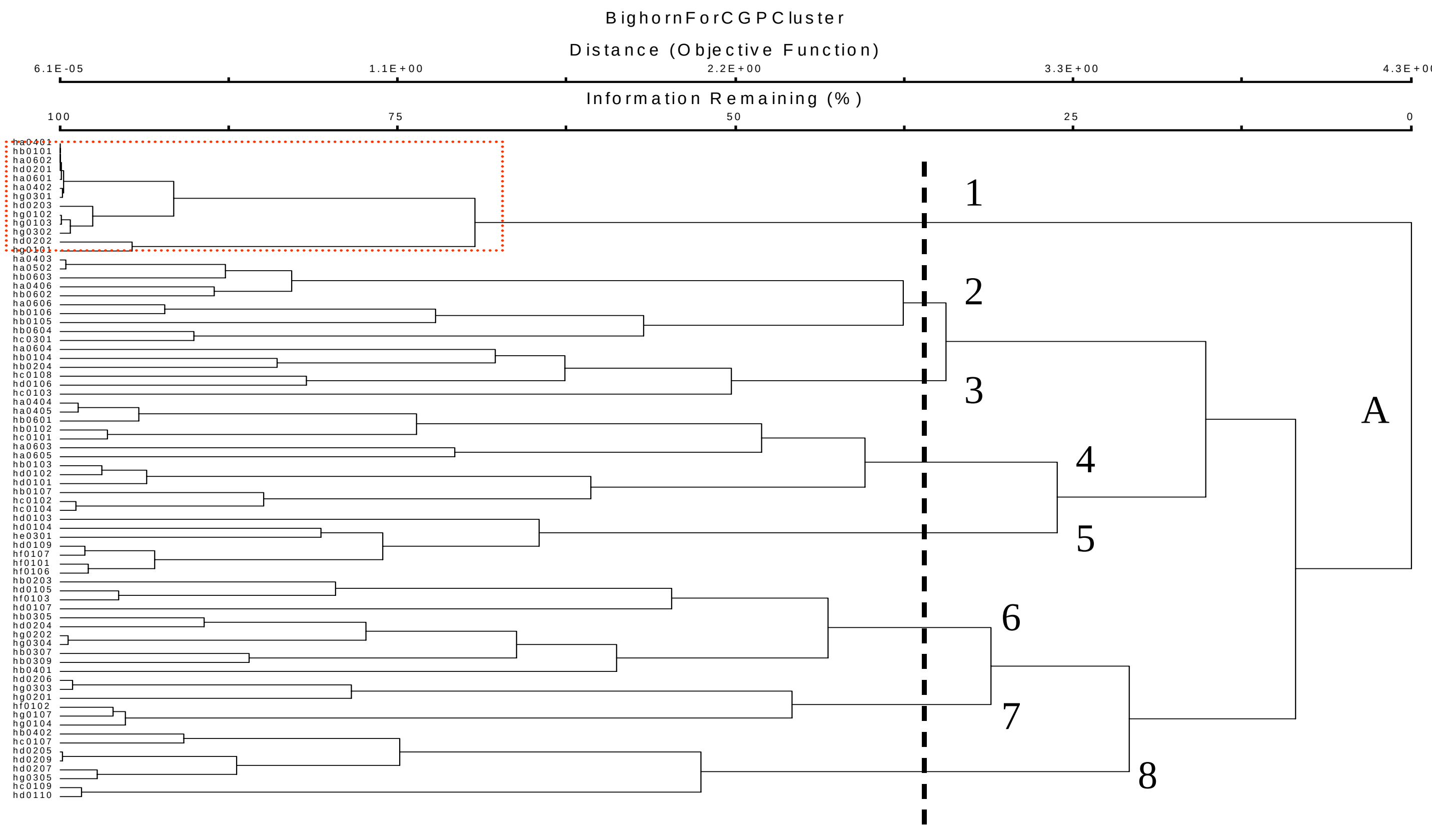
Data: Each 6th level HUB was analyzed using map overlays to calculate the area (acreage or hectares) or proportion (%) of its land occupied by each driver combination. For example, while the entire HUB may be influenced by a snow dominated precipitation regime (Ps), it may have both calcareous (Ca) and non-calcareous bedrock (Cn) regions, and only certain areas of the HUB may have been glaciated (Qg) and all other areas are unglaciated (Qn). The HUB was then analyzed to determine the area with (1) calcareous bedrock, non-glaciated and snowmelt precipitation, (2) calcareous bedrock, glaciated and snowmelt precipitation, (3) non-calcareous bedrock, non-glaciated and snowmelt precipitation, and (4) non-calcareous bedrock, glaciated and snowmelt precipitation. A similar analysis was then performed for each of the 74 6th level HUBs in the Bighorn National Forest, for the twelve possible driver combinations. The acreage and percentage of the watershed with each driver combination was determined from GIS coverage of watershed elevation, bedrock geology, and quaternary geology maps.

An example of the data required in spreadsheet format for analysis is given in Table 4.3. Each row is a 6th level HUB with its unique identification code. The columns represent one driver combination and are presented as percentage of each HUB's area covered by each driver combination. For multivariate analysis each HUB is a "stand" or "plot". Driver combinations are equivalent to "species". Thus, there are 74 "plots" and 12 "species" in the analysis, which classifies "plots" according to "species" similarity.

Table 4.3. Example data setup in spreadsheet format for cluster and ordination analyses in PC-ORD (McCune and Mefford 1999). Only six of the 12 driver combinations for the Bighorn National Forest are shown. The number 74 in column 1, row 1, refers to the number of HUBs in the data set ("plots") and the number 12 in column 1, row 2 is the number of driver combinations ("species"). The Q's in row three indicate that the data in each column are quantitative. In column 1 are unique codes for each HUB. Data in cells are the percent of each HUB area with a particular driver combination. Ca is calcareous bedrock, Qg is glaciated landscape, Qn is non-glaciated, Pr, Prs, and Ps are rain, rain and snow, and snow driven precipitation regimes, respectively.

74	HUBs					
12	Driver comb.					
	Q	Q	Q	Q	Q	Q
HUB CODE	CaQgPr	CaQgPrs	CaQgPs	CaQnPr	CaQnPrs	CaQnPs
ha0401	0.00	0.00	3.29	0.00	0.00	0.00
ha0402	0.00	0.00	5.35	0.00	0.00	1.65
ha0403	10.23	55.56	15.76	0.62	4.57	0.01
ha0404	0.00	27.80	34.90	0.00	0.40	0.19
ha0405	0.00	20.93	29.28	0.00	0.00	1.26
ha0406	2.82	46.47	18.46	0.96	23.32	3.89
ha0502	14.20	54.18	22.41	0.33	4.66	0.82
ha0601	0.00	0.65	5.48	0.00	0.00	0.00
ha0602	0.00	0.03	2.37	0.00	0.00	0.00
ha0603	0.00	8.89	50.59	0.00	0.05	1.04
ha0604	11.43	32.88	2.91	2.19	31.73	2.63
ha0605	0.29	11.04	19.26	0.03	15.57	1.92
ha0606	2.50	20.11	10.86	1.20	21.63	12.47

Figure 4.6. Agglomerative cluster analysis of Bighorn National Forest 6th level HUBs. Cluster analysis was performed using Sørenson Distance, measured as percent dissimilarity between HUBs. The cluster analysis was created using Average Linkage Methods. Labels for HUBs are on left and indicate the last six letters of each 6th level HUB code, and all lead with an "h". On the x axis labeled Information Remaining (%), 100 indicates 100% similar, and 0 no similarity. The red dashed box indicated the small group of HUBs separated at the first division (A) in the analysis. The heavy dashed line is at 35% similarity, and the numbers 1 through 8 are the final clusters chosen from this analysis. Cluster 1 includes HUBs ha0401 through hg0101, cluster 2 includes HUBs ha0403 to hc0301, cluster 3 includes HUBs ha0604 to hc0103, etc.



Analyses: Agglomerative cluster analysis was chosen because programs to perform this type of classification are readily available, whereas programs to perform divisive cluster analysis, e.g., TWINSPAN, are less readily available. In our analysis, the agglomerative and divisive cluster produced nearly identical results. Agglomerative cluster analysis is based upon the fusion of single entities (HUBs) or clusters of HUBs into larger groups. The two HUBs or clusters that most resemble each other are always fused, but the definition of "similarity" between HUBs or groups varies depending upon the methods chosen (van Tongeren 1995). Results of cluster analysis are typically presented hierarchical trees, commonly called dendrograms (Ludwig and Reynolds 1988) that illustrate the statistical relationships among HUBs or groups of HUBs. Relationships among HUBs were analyzed using Sørenson Distance to measure percent dissimilarity of the proportion of each HUB covered by each driver combination. The Sørenson Distance was chosen because of its usefulness for community ecology data (McCune and Mefford 1999), and because the resulting scale from 0 to 100% is easy to interpret. The cluster analysis was created using the Average Linkage method, which is the most commonly used method in ecology (van Tongeren 1995) and is recommended for hierarchical classification (Sneath and Sokal 1973).

All analyses were performed with PC-ORD (McCune and Mefford 1999). On the X-axis in Figure 4.6, Information Remaining (%) is the similarity measure, with 100 indicating 100% similarity, and 0 indicating 0% similarity. There is no single objective approach for determining the percent similarity or dissimilarity at which meaningful ecological differences between HUBs occur. However, two general approaches can be used. One is to follow the dendrogram splits until the desired number of HUB groups or clusters is reached. The second is to choose a percent similarity /dissimilarity from the axis scale and all HUBs clustered with greater similarity are considered "homogenous" groups.

There are benefits and problems associated with each approach. Following the branches in the dendrogram is objective and straightforward. The entire data set is broken into two groups based upon the dendrogram branch pattern. Each of the two groups is then broken into two groups, and each broken again. The resulting eight groups are the final groups or clusters. However, when the first or second splits divide HUBs into a very large and a very small group, this approach becomes unwieldy. For example, in the cluster analysis used for wetlands in the Bighorn Mountains the first division separated a very large from a very small number of HUBs (Fig. 4.6). Further subdivision of the cluster that begins at the top of the graph and contains HUBs ha0401 through hg0101, is not important in this analysis, because these HUBs have a much higher level of similarity to each other than to other HUBs and groups of HUBs. Therefore, we selected 35% similarity as the cutoff in our analysis to arrive at eight cluster groups that was our *a priori* number of clusters that we wished to work with.

Indirect ordination, using detrended correspondence analysis (DCA), was used for further analysis of the data set. DCA is widely used among ecologists because it provides an effective approximate ordination solution (Ter Braak 1995). DCA plots HUBs along continuous axes. While distinctive groups can be found, the goal of indirect ordination (DCA) is to show the relationships (structure) of the entire data set. HUBs with the most similar percent of their area in similar driver combinations are plotted most closely together. In addition, the centroid of each driver combination is plotted on the diagram showing where its influence is greatest. HUBs plotted near the centroid of one or more driver combinations will have a high percentage area in that driver combination.

The classes generated from the cluster analysis were used to create a map identifying eight groups of HUBs in the Bighorn National Forest (Fig. 4.7). HUBs in the same class should have the most similar percentage of their area in particular driver combinations. We also created GIS data sets of the acreage of wetland and riparian ecosystems in each HUB, and the percent of each HUB's area that was wetland and riparian.

U.S. Fish and Wildlife Service National Wetlands Inventory (NWI) maps are available for many Forests, and can be obtained in digital format. These maps use the Cowardin et al. (1979) classification system. However, the digital NWI maps cover only a portion of the Bighorn National Forest. They can be used where National Forest or other resource maps are unavailable.

Results: The first division in the cluster analysis presented in Figure 4.6 set separates two unequal sized groups of HUBs. There is 0% similarity in the thirteen group 1 HUBs with the other 61 HUBs. These thirteen HUBs, bounded by the red dotted line on Figure 4.6, occur at high elevation on non-calcareous rocks. Because group 1 was so small, and had relatively high internal homogeneity, further subdivision was not warranted. The remaining 61 HUBs are divided into groups at a similarity of ~35% as indicated by the heavy dashed line on Figure 4.6. Each of the eight clustered groups of HUBs is labeled on Figure 4.6. The location in the Bighorn National Forest of HUBs in these eight clusters is shown in Figure 4.7.

HUBs in clusters 1 and 4 occur in the highest elevation portion of the Bighorn Mountains. HUBs in clusters 2, 3, and 8 occur at the lowest elevations of the Bighorn National Forest, in foothill locations. Thus, elevation has a key role in determining the characteristics of HUBs based upon the driver combinations chosen. Figure 4.8 illustrates the dominance of driver combinations by area in the study region.

Table 4.4 presents the mean percentage of each driver combination for HUBs in clusters 1-8. Clusters 1, 4, and 5 include HUBs with snow dominated precipitation regimes, with cluster 1 dominated by non-calcareous and glaciated, cluster 4 calcareous glaciated, and cluster 5 non-calcareous and non-glaciated areas. Clusters 2 and 7 have a rain and snow precipitation regime, with cluster 2 in calcareous bedrock, and cluster 7 in non-calcareous bedrock. Cluster 8 HUBs have a predominantly rain driven precipitation regime in non-calcareous bedrock areas. Clusters 3 and 6 have a mixed rain and rain and snow precipitation regime, with three occurring in glaciated areas and six occurring in non-calcareous areas.

Discussion: These analyses indicate that the driver combinations provide a good first step for identifying the physical factors determining where the highest concentrations of riparian and wetland areas may occur in a National Forest. The analysis can be objective and quantitative as demonstrated here. However, it is necessary to have a data set for the resource values to be analyzed. In this case a riparian data set was available for the Bighorn National Forest. However, this data set could be much improved if major wetland types were identified. In addition, any GIS data on the distribution of rare riparian or wetland plants, animals, or plant communities could also be linked to the analyses. Other GIS layers could include anthropogenic impacts to identify where land uses are in direct conflict with areas of high wetland and riparian density, and the distribution of certain plants, animals, and communities.

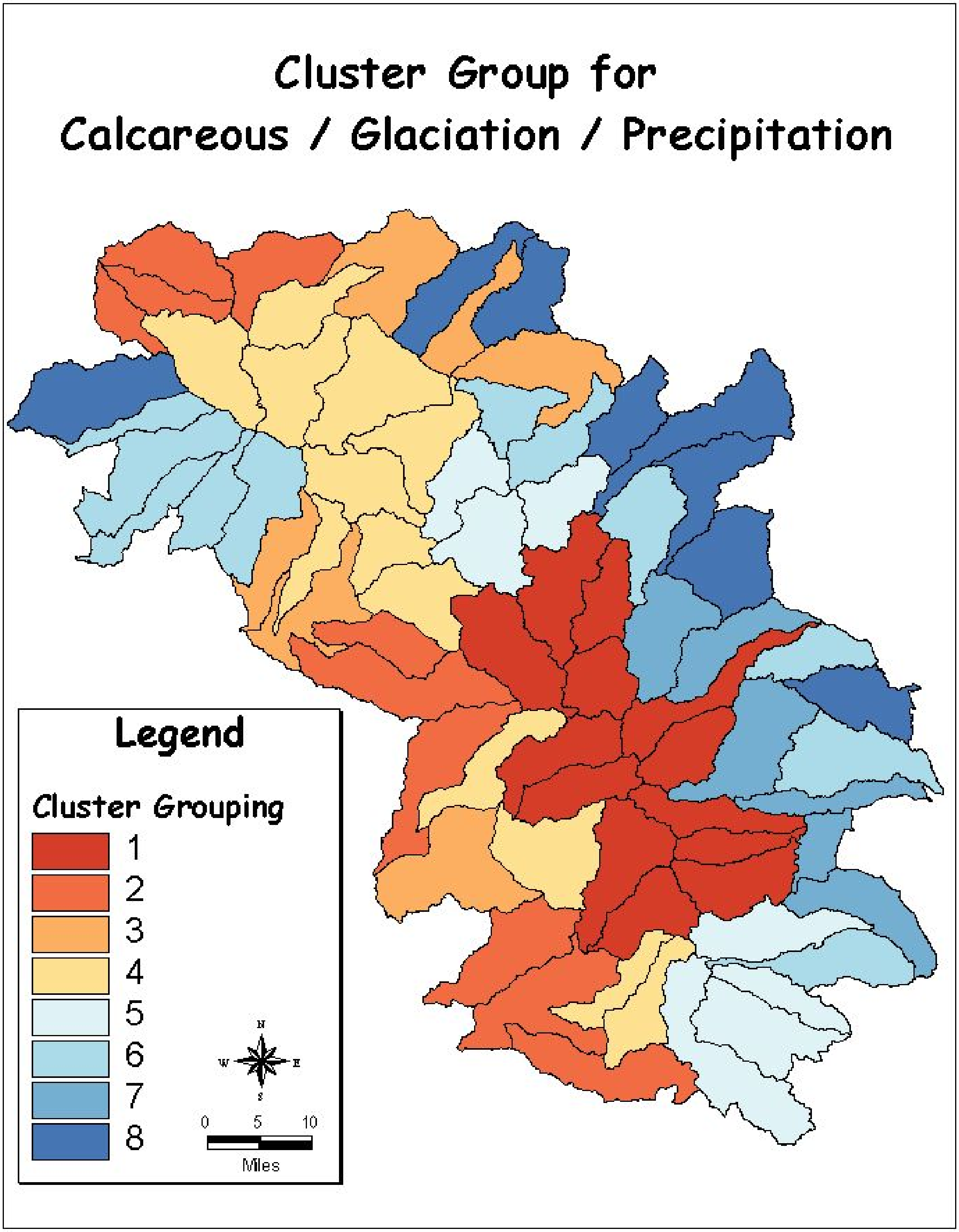


Figure 4.7. Map depicting the classification of HUBs as determined using agglomerative cluster analysis, based upon their driver combinations.

Table 4.4. Mean percent area of driver combinations in HUBs in clusters 1-8. Bolded numbers are the driver combinations that cover the largest areas. Ca is calcareous bedrock, Qg is glaciated landscape, Qn is non-glaciated, Pr, Prs, and Ps are rain, rain and snow, and snow driven precipitation regimes, respectively.

Cluster	CaQgPr	CaQgPrs	CaQgPs	CaQnPr	CaQnPrs	CaQnPs	CnQgPr	CnQgPrs	CnQgPs	CnQnPr	CnQnPrs	CnQnPs
1	0.00	0.28	1.63	0.00	0.02	0.19	0.00	3.41	**82.40**	0.01	4.87	7.19
2	4.76	**38.89**	13.58	0.86	**20.02**	11.05	2.34	1.01	4.46	0.14	1.00	1.89
3	10.19	**29.66**	9.47	8.19	9.30	1.62	**16.84**	2.22	0.42	9.22	2.61	0.25
4	0.22	15.29	**41.61**	0.02	2.73	5.91	1.25	2.28	15.81	0.08	4.41	10.40
5	0.15	9.88	7.33	0.00	3.47	3.94	0.00	3.41	10.31	0.00	5.83	**55.68**
6	3.71	**13.76**	4.20	1.41	2.99	1.46	**15.18**	16.21	2.16	**12.88**	**17.16**	8.88
7	0.00	5.07	0.00	0.00	1.14	0.00	2.99	**15.86**	16.04	2.18	**39.46**	17.25
8	0.91	8.96	1.43	1.03	2.11	0.37	**29.80**	4.24	0.13	**46.60**	4.41	0.00

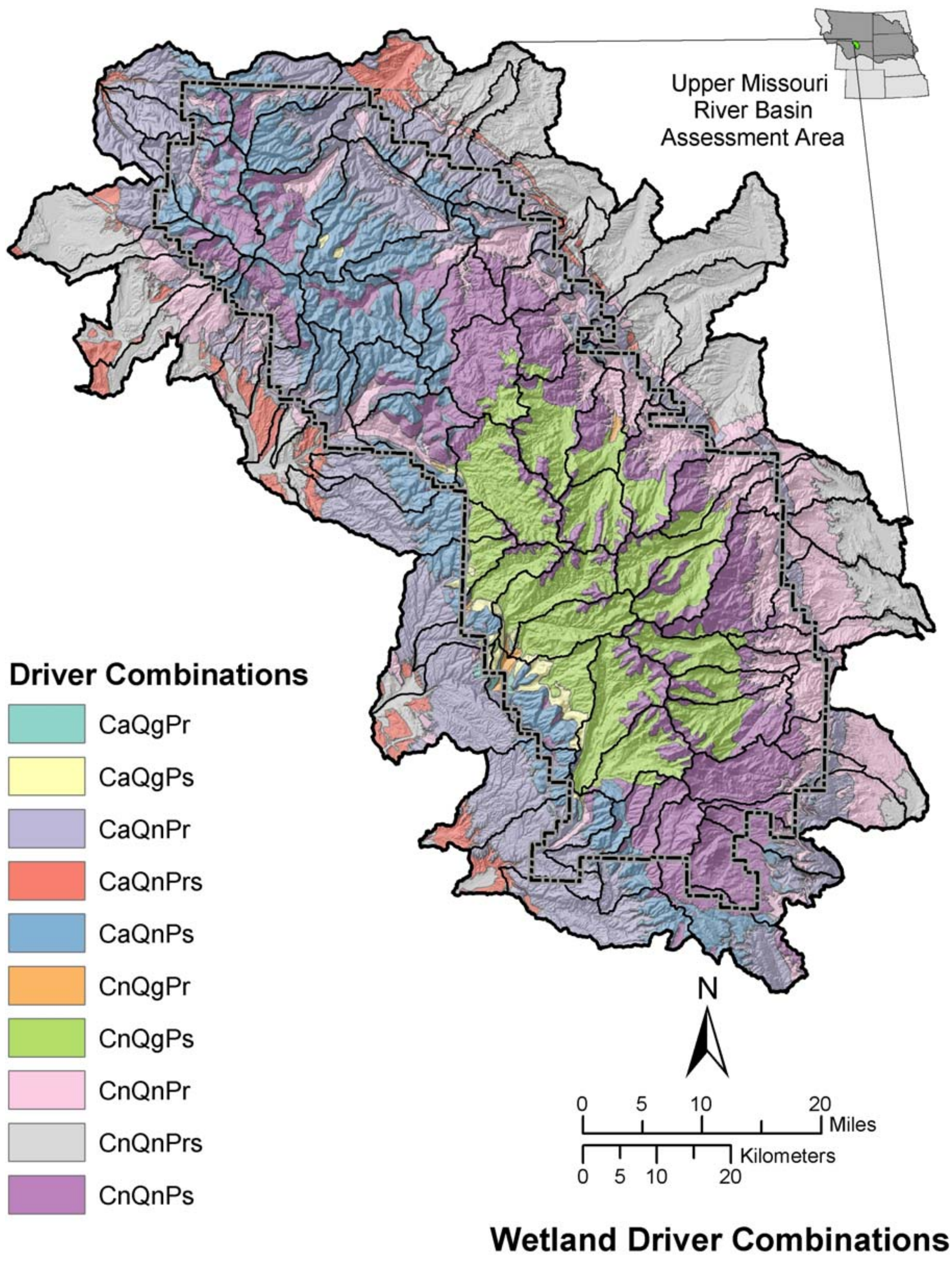


Figure 4.8. Area dominated by each driver combination of geology(Ca/Cn), glaciation (Qg/Qn), and precipitation (Prs/Ps/Pr) in the Bighorn National Forest assessment area.

CHAPTER 5

DRIVERS AND RELATED FACTORS FOR ADDRESSING ANTHROPOGENIC INFLUENCES ON AQUATIC, RIPARIAN, AND WETLAND RESOURCES

Introduction

Human activity has transformed the Earth's surface, changed atmospheric conditions, and altered aquatic ecosystems, which are now under great stress (Campbell 2001). Understanding the influences of these human activities on the landscape is an essential part of conducting an ecological assessment. For this assessment, anthropogenic influences refer to alterations to the land, which have been caused by Euro-American settlers (Dissmeyer 2000; Wohl 2001). The management related activities encompass a wide array of factors that influence aquatic, riparian, and wetland resources both directly and indirectly over time. The purpose of this chapter is to define the appropriate anthropogenic activities and identify the analyses that include both the extent and duration of influences on aquatic, riparian, and wetland resources.

Although indigenous humans had some influence on aquatic, riparian, and wetland resources in the Rocky Mountain Region, it is believed to be minor and on a very limited basis (Meyer and Knight 2001; Wohl 2001). These people were primarily nomadic and lived in small family groups dispersed on the landscape. Moving with available food sources seasonally and as supplies became depleted; they had minimal influence on aquatic, riparian, and wetland resources for more than a short period of time. As a result, this protocol will not address pre-European settlement from a human influence stand-point, unless new information proves otherwise.

Activities such as domestic grazing, road construction and maintenance, and reservoir development may influence both terrestrial and aquatic ecosystems, in several different aspects of their form and function (Rinne 1999; Wohl 2001). In addition, both temporal and spatial considerations must be made, and both positive and negative influences considered for management decisions (Jensen and Bourgeron 2001). This protocol strives to identify spatial and temporal influences of anthropogenic activities for the purpose of making sound land management decisions under appropriate U.S. Forest Service mandates.

In order to focus on pertinent activities and resulting influences, an effort has been made to identify anthropogenic activities, which have in the past, or are having or could have a significant influence on aquatic, riparian, and wetland resources across the region (Wohl 2001; Dissmeyer 2000) (Table 5.1). Certain activities may affect aquatic, riparian, and wetland resources in a river basin at one or more scales, but have no bearing on Forest Service administered lands or that the Forest Service has no jurisdiction over. As a result, these activities would be considered to be inappropriate measurements for this assessment.

Anthropogenic activities from Euro-American settlers have occurred in the Rocky Mountains since the late 1700s and early 1800s (Morgan 1986; Meyer and Knight 2001; Wohl 2001). However, it is difficult to generalize activities as currently influencing aquatic, riparian, and wetland resources. Therefore, we have chosen to separate activities and the resulting influences into appropriate categories, which can be addressed at different spatial and temporal scales. For example, activities that today still influence aquatic, riparian, and wetland resources, such as beaver trapping and logging tie drives, may have predominantly occurred more than 100 years ago.

There are risks associated with management activities on aquatic, riparian, and wetland resources. Environmental sensitivity, scale of the activity, and the relative rarity of resources in part determine risk. As part of addressing anthropogenic influences, measures of risk should be identified by incorporating landscape drivers and anthropogenic activities currently and historically occurring on the landscape. Inferring influences to aquatic, riparian, and wetland resources from management activities at scales broader than the reach/site scale will only occur if the inferences can be justified through the literature and quantified by more rigorous validation.

A total of four scales have been recognized for this assessment (see Fig. 1.3). The effects of anthropogenic activities may be best understood at one or more of these scales, depending on their influence on aquatic, riparian, and wetland resources. Generally, the effect of a particular influence becomes more inferred as the analysis scale becomes larger. For example, it is appropriate to analyze the effect of a water diversion at the reach/site scale for a particular species, life-stage, etc. However, at the landscape scale this information is too narrowly focused to be meaningful. Each anthropogenic influence will be evaluated separately to determine the appropriate scale and measurement to be used for the analysis.

Quantitative measurements provide a relatively high level of accuracy, often preferred in an assessment analysis. However, quantitative measurements of anthropogenic effects may not be currently available or appropriate at all scales and for all activities. Qualitative and quantitative procedures will be identified, in order to provide a realistic basis for defensibility and appropriateness for decision-making. As part of the adaptive nature of this process, validation monitoring will occur to address specific questions and assumptions of qualitative estimates as well as quantitative measurements (Kershner 1997).

The ability for the U.S. Forest Service to have measurable influence over anthropogenic activities and their effects is dependent on the mandates and laws, under which it operates (USDA Forest Service 1983). We currently have limited influence on activities that occur outside our jurisdiction, although our activities may influence aquatic, riparian, and wetland resources. However, activities such as road placement, grazing allotment management, and water diversions may be influenced on a forest or regional basis that beneficially influence aquatic, riparian, and wetland resources. All anthropogenic activities influencing aquatic, riparian, and wetland resources in the assessment area will be identified, but only those over which we have influence will be analyzed.

The Process

A rational pathway for addressing the relationships between ecological processes and anthropogenic influences is described in this chapter. We address the anthropogenic influences and their relationship to ecological processes. Issues of scale, effects, and temporal scales will also be addressed.

In order to provide a logical progression from identifying anthropogenic influences, understanding the Forest Service's role, the temporal and spatial context, and how we measure activities influences, it was necessary to provide a description for each activity (see *Anthropogenic Influences used in Conducting Multiple Scale Aquatic, Riparian, and Wetland Ecological Assessments,* Winters et al. 2003, in draft). Each description provides a brief historical account and potential influence on aquatic, riparian, and wetland resources, potential effects on specific components, and how they will be measured at a particular scale. These descriptions were constructed, reviewed, and modified by the team until agreement was reached by all team members as to the applicability of each activity in addressing anthropogenic influences for all aspects of aquatic, riparian, and wetland components. The assessment will incorporate the actual measurements at the various identified scales to determine areas of intense as well as limited anthropogenic influences. This process was discussed with the Terrestrial Ecosystem Team to ensure consistency with the analysis being conducted in the two assessments.

By evaluating these relationships, we hope to provide managers with the information necessary to make informed management decisions regarding the protection, enhancement and recovery of species, and ecosystems related to aquatic, riparian, and wetland resources.

Categories of Ecological Concern

Various types of anthropogenic activities influence aquatic, riparian, and wetland resources in the Rocky Mountains (Zimmerman and Ward 1984; Wohl 2000, 2001). Many of these activities are currently, or have historically occurred in the Rocky Mountain Region of the Forest Service. A total of 26 activities were identified for this process, based on the past and current activities in the study area and their influence on aquatic, riparian, and wetland resources (Meehan 1991; Waters 1995; Zeedyk 1996; Wohl 2001) (Fig. 5.1). We also grouped activities into seven "use categories" (Table 5.1). These categories represent activities that represent similar management activities, or have similar influences. For example, in the water use category, diversions, reservoirs, and ditches all modify the hydrology of aquatic, riparian, and wetland resources. In addition, they are all uses that involve manipulating the quantity of water for the benefit of man.

The temporal context associated with specific activities was identified. While the influence of current activities are readily apparent on the landscape, historic activities such as beaver removal are not as evident, although they may have had a significant effect on aquatic, riparian, and wetland resources (Wohl 2001). It is important to address all the activities associated with management influences if a true picture of anthropogenic influences is to be developed.

Explanation of Categories of Ecological Concerns

In order to address the influence that the anthropogenic influences identified have on aquatic, riparian, and wetland resources, we have identified several "categories" of ecological concerns that will be addressed for each activity (Fig. 5.1). These categories of ecological concern represent direct changes to the physical form and function (e.g., channel characteristics and hydrology), biological communities (e.g., introduction of non-native species), or chemical components of aquatic, riparian, and wetland resources (Meehan 1991; Waters 1995; Dissmeyer 2000; Wohl 2001). Specific ecological concerns include:

(1) Hydrology – Anthropogenic activities that remove or alter water flow from wetlands and stream systems influence a variety of different components of aquatic, riparian, and wetland resources, including sediment transport, channel and vegetation maintenance, life-history timing, and habitat quantity and quality.

(2) Channel Condition – Direct and indirect alterations of stream channels influence different components of aquatic, riparian, and wetland resources, including sediment transport, channel and vegetation maintenance, life-history timing, and habitat quantity and quality, and can alter hydrology, habitat conditions, channel confinement, sediment dynamics, and biological communities related to aquatic, riparian, and wetland resources.

(3) Water Quality – Water quality concerns are realized directly from effluent from mining audits, road salting, and other activities, as well as indirectly from changes in attributes such as water temperature resulting from alteration in riparian shading.

(4) Biotic Condition – The introduction of non-native flora and fauna has been shown to have significant effects on native communities, as well as effects on water quality, channel stability, and hydrology.

(5) Riparian and Wetland Condition Anthropogenic activities have a variety of effects on riparian and wetland soil and vegetative characteristics. These effects in turn have a number of influences on other associated characteristics of the physical and biological characteristics of these environments.

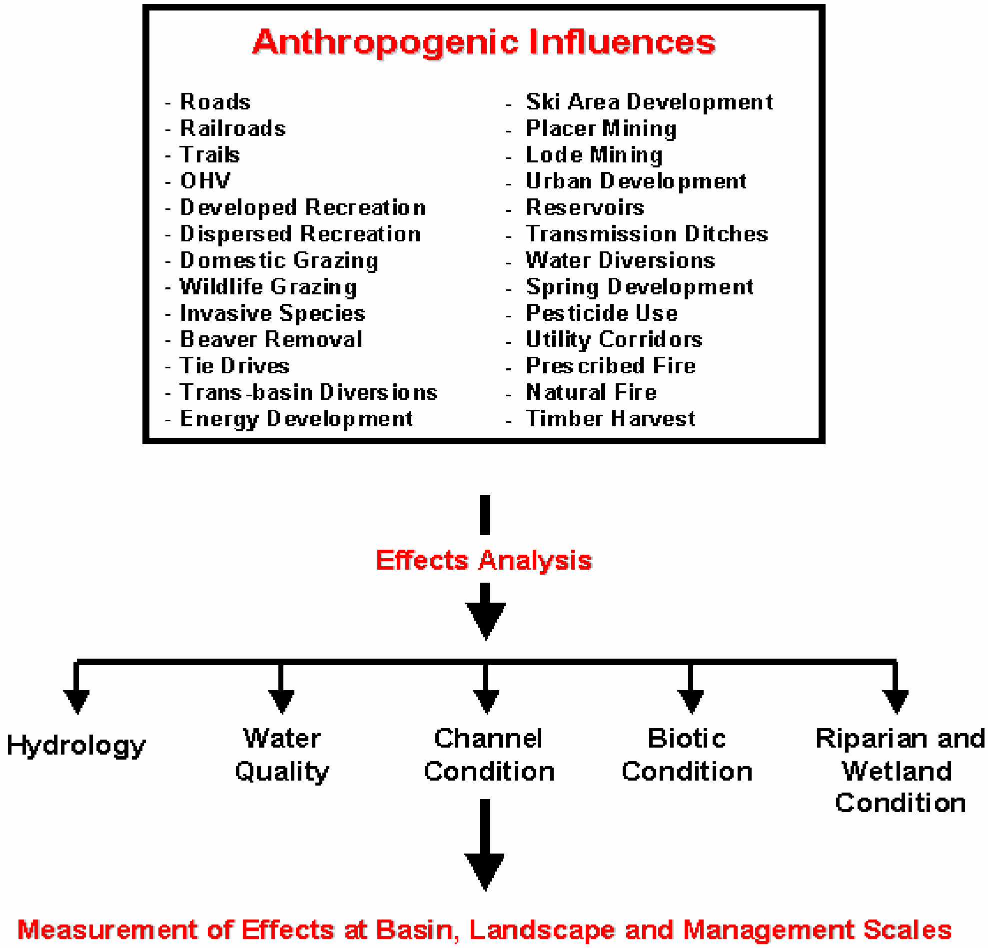


Figure 5.1. Summary figure of the anthropogenic activity assessment.

Table 5.1. Anthropogenic activities identified for analysis for the aquatic, riparian, and wetland assessments.

USE CATEGORY*	ACTIVITY**	USFS JURISDICTION***	TEMPORAL CONTEXT****
Water Use	Stream Diversions	Yes	H/C/F
Water Use	Reservoirs	Yes	H/C/F
Water Use	Transmission Ditches	Yes	H/C/F
Water Use	Transbasin Diversions	Yes	H/C/F
Water Use	Spring Development	Yes	H/C/F
Transportation	Roads	Yes	H/C/F
Transportation	Trails	Yes	H/C/F
Transportation	Railroads	Yes	H/C/F
Transportation	Off-Road Vehicle Use	Yes	C/F
Recreation	Developed Recreation	Yes	H/C/F
Recreation	Dispersed Recreation	Yes	H/C/F
Recreation	Ski Area Development	Yes	H/C/F
Biological	Invasive Species	Yes	H/C/F
Biological	Beaver Removal	Yes	H/C/F
Biological	Pesticide Use	Yes	H/C/F
Mineral Extraction	Hard rock Mining	Yes	H
Mineral Extraction	Placer Mining	Yes	H/C/F
Mineral Extraction	Energy Development	Yes	H/C/F
Vegetation Management	Domestic Grazing	Yes	H/C/F
Vegetation Management	Wildlife Grazing	Yes	H/C/F
Vegetation Management	Commercial Timber Harvest	Yes	H/C/F
Vegetation Management	Natural Fire	Limited	H/C/F
Vegetation Management	Prescribed Fire	Yes	C/F
Vegetation Management	Tie Drives	Yes	H
Urbanization	Transmission Corridors	Yes	H/C/F
Urbanization	Urbanization	Limited	H/C/F

* *Resource use category related to aquatic, riparian, and wetland resources.*
** *Management activity to be addressed.*
*** *Does the U.S. Forest Service have the ability to influence the activity with current mandates?*
**** *Historic activities having current effects on aquatic, riparian, and wetland resources (H/C); current activities affecting aquatic, riparian, and wetland resources (C/C); current activities that will have future effects to aquatic, riparian, and wetland resources (C/F).*

An example of an effects table for ecological concerns is presented in Table 5.2, from the discussion on railroads in the companion document: *Anthropogenic Influences used in Conducting Multiple Scale Aquatic, Riparian, and Wetland Ecological Assessments* (Winters et al. 2003, in draft). The table is divided into the specific ecological concerns identified above. The effects of railroads on each category are identified and listed in the appropriate column. This process provides a logical sequence for identifying how to measure these effects at various scales in the next step.

Table 5.2. Example of anthropogenic impacts showing the potential effects of railroads on aquatic, riparian, and wetland resources.

EFFECTS CATEGORY	INFLUENCE
Hydrology	• Elevated track prisms can concentrate surface runoff along track ditches and eventually through culverts, leading to erosion and stream sedimentation. • Wetland hydrology can be intercepted, potentially creating new wetlands and abandoning historic sites.
Water Quality	• Increased erosion and sedimentation from cut and fill slopes, and stream crossings resulting in reduced aquatic habitat. • Increased erosion and sedimentation from constricted stream channels, where current velocities are increased. • Ground and surface water contamination from petroleum and chemical spills, equipment used for maintenance, and creosote impregnated railroad ties. • Catastrophic contamination from derailment.
Channel Condition	• Constricted channels from track prism impingement. • Decreased instream habitat and complexity from sedimentation in slower velocity areas. • Changes in woody material delivery from presence of track prism and interception from upland recruitment. • Streambank instability from changes in channel form from impingement.
Biotic Condition	• Changes in complexity and structure of stream banks from impingement, rip-rapping, and channel narrowing. • Decrease in complexity and quality of instream habitat from increased sedimentation. • Decreased woody debris habitat and habitat forming features. • Habitat for invasive plants on disturbed soils. • Transport of invasive species seeds.
Riparian & Wetland Condition	• Direct vegetation and soil loss from track prism construction and presence. • Alteration of wetland function from ground and surface water interception.

Measurements of Anthropogenic Activities

Once the specific activities and influences on aquatic, riparian, and wetland resources are identified, the final step is to identify specific measurements that can be used to assess the extent and abundance of each activity separately or in aggregate. Each measurement has to be appropriate for the scale examined, in terms of comparisons across the scale used and the ability to quantify that specific topic. At broader scales, such as the basin scale (millions of square acres), it may be appropriate to address an activity in terms of trends over time, or a more narrative account of the activity. Quantitative information may not be available or appropriate at this scale. However, at smaller scales (100s to 1000s of acres), more quantitative measures are important for comparisons across similar landscape areas (e.g., 6th level HUBs or at the management scale). In this case, "dimensionless" values, or values that are comparable across landscapes or watersheds regardless of size are important (e.g., miles of stream/acre of watershed). Table 5.3 illustrates an example of actual measurements to be used for railroads in this assessment. For this assessment, we will focus on quantitative measurements as much as possible for the landscape and management scales. It may be also pertinent to derive historical and distributional data for the basin scale. However, the intent will be to use this information to strengthen the information for the smaller scales only. Although we are not conducting field analysis at the reach/site scale, we provide information on how these measurements could be addressed. This information follows the logical path we have taken, and will help specialists understand the relationships with larger scales. They will also help the Region in defining protocols for projects and planning.

Anthropogenic activities have had a tremendous effect on aquatic, riparian, and wetland resources in the Rocky Mountain Region, and will continue to influence them in the future (Wohl 2001). We have provided a logical path for addressing historical and current activities that influence aquatic, riparian, and wetland resources, including the type and extent of activities, effects analysis and measurements to quantify them at different scales (Table 5.3). This process was designed to promote consistency and defensibility across administrative boundaries of the USDA Forest Service. By incorporating several scales to this exercise, we will be able to expand our analysis beyond the administrative boundaries that limit our scope of comparisons.

Table 5.3. Measurements of railroad influence on aquatic, riparian, and wetland resources at the appropriate scale.

Scale	Evaluation Criteria
Basin	• Historical account of railroad activity and relationships with population trends.
Landscape (4th level HUB)	• Total miles of historic (including abandoned) and current railroad tracks within and outside of Forest or Grassland boundary/4th level HUB. • Total miles of track in valley bottom (miles of track in valley bottom/miles of track/4th level HUB. • Total stream crossings/stream mile/4th level HUB.
Management (6th level HUB)	• Total miles of track in valley bottom as a comparison with HUB size (miles of track in valley bottom/stream mile/6th level HUB. • Stream crossings/stream mile/6th level HUB.
Reach/Site	• Culvert effectiveness, in terms of sediment transport and biotic passage • Direct measurement of erosion from cut and fill slopes, bank instability, and stream crossings. • Measurement of soil and water contamination. • Identification and measurement of channel constriction and modification. • Measurement of riparian and wetland loss from track prism. • Analysis of invasive plant populations.

Valley Floor Delineation

Accurate mapping of valley floor environments is also necessary to analyze the nature and extent of natural and anthropogenic disturbance, and comparison of management strategies (Manning and Maynard 1993) (Fig 5.2). This information is important because valley floor ecosystems are where the majority of anthropogenic impacts are concentrated, as well as where most aquatic, riparian, and wetland resources are located. Therefore, the aquatic, riparian, and wetland assessments require delineation of these environments using GIS.

Earlier assessments, such as the Southern Appalachian Assessment-Aquatic Technical Report (SAMAB 1996) utilized a 100-foot buffer around the existing stream coverage as a method of delineating riparian areas. While this is an accepted standard for analyzing disturbance and impacts upon stream channels (Roth 1996), a number of concerns arise when applying this method to riparian and wetland environments. The concerns include:

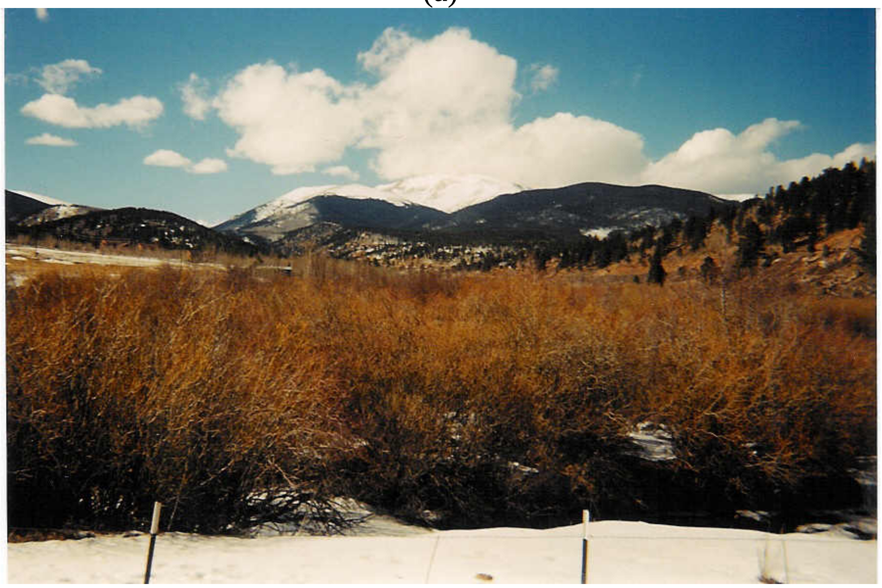
(1) The underestimation of riparian and wetland area in broad, glacial valleys wider than 200 feet.

(2) Riparian and wetland communities that exist in unchannelized or intermittent stream valleys are not included in the stream coverage.

(3) The buffer does not account for potential changes in the fluvial system that would result in a change in the spatial extent of aquatic, riparian, and wetland ecosystems. This includes events that would alter channel morphology and position, such as a large magnitude flood event, lateral accretion, landslide damming of a stream channel, bank erosion, beaver reintroduction, and increases in sediment load, etc.

For the purpose of the ARWA, the valley floor is considered to be a stable environment containing dynamic components such as perennial and intermittent streams, primary and secondary stream channels, active terraces and floodplains. GIS-based boolean query of the existing stream coverage, a 30-meter USGS digital elevation model (DEM), and a stream network created from the DEM are utilized to define these areas from the DEM. This method consists of four steps (Fig. 5.3), including:

(a)



(b)

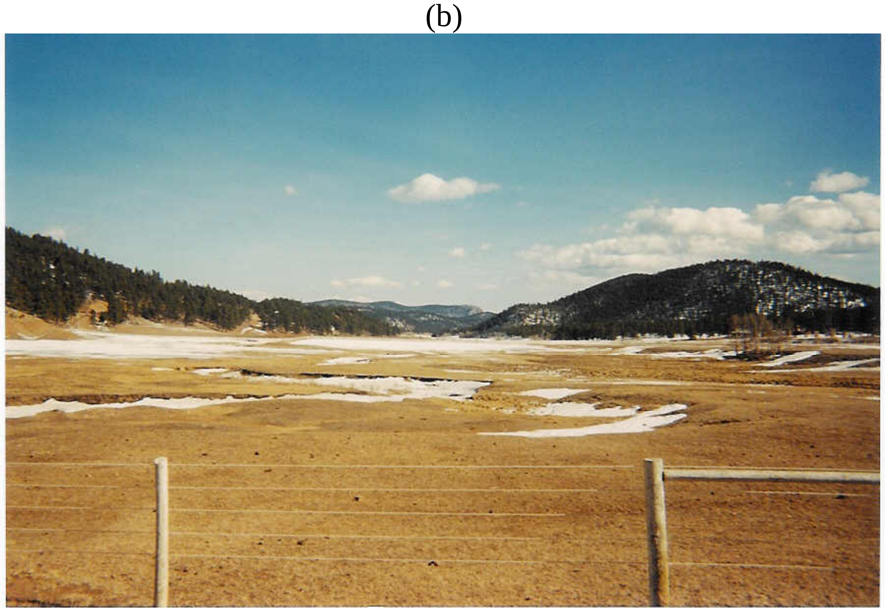


Figure 5.2. Images are from the same location on Deer Creek, CO. (a) View upstream of an undisturbed, beaver occupied valley floor. (b) View downstream of a grazed valley floor and impacted stream channel from the same bridge as in top photo. The downstream reach is incised, and has a much higher width/depth ratio.

(1) Existing stream coverage is buffered on each side by 30 m. If a point falls within this buffer, it is considered to be within the area of influence for the stream and a part of the valley floor.
(2) A slope map is derived from the DEM using ArcInfo Workstation GIS. All grid cells with slopes ≤6% are flagged as potential valley floor cells (Manning and Maynard 1993).
(3) Streams are categorized using the aforementioned gradient breaks. The categories are high gradient (gradient ≥4%), moderate gradient (gradient ≥2% and <4%), and low gradient (gradient <2%). Each of the streams is assigned an analysis window equivalent to maximum valley floor width. Low gradient streams are assigned a maximum valley width of 300 meters, moderate gradient streams are assigned a maximum valley width of 200 meters, and high gradient streams are assigned a maximum valley width of 120 meters. These values were derived from empirical observations of valleys within the Bighorn National Forest (D. Scaife oral commun., 2002).
(4) If a grid cell with a slope ≤6% is within the analysis window designated for each stream gradient category, it is considered to be a part of the valley floor.

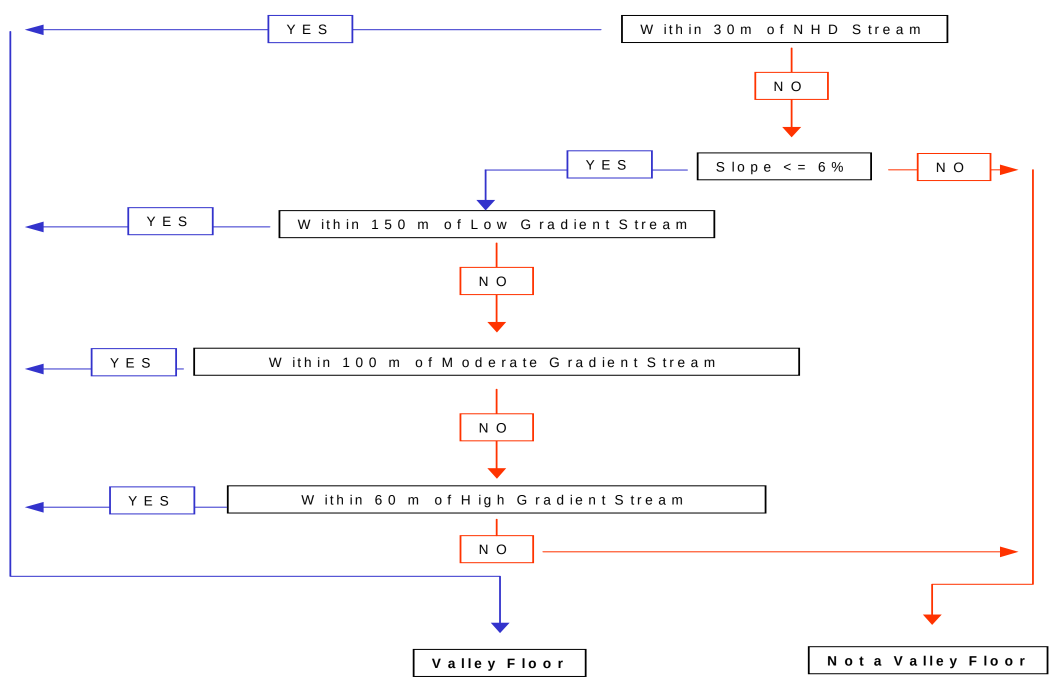


Figure 5.3. Conceptual model of the valley floor delineation.

Anthropogenic Influence Analysis: Process and Portrayal

The Aquatic, Riparian, and Wetland Assessment (ARWA) utilizes a multiple scale, hierarchical analysis for the purpose of portraying the complex physiographic, ecological and anthropogenic characteristics of the Rocky Mountain Region's National Forests. Numerous anthropogenic activities occur throughout the basin, landscape, management and reach/site spatial scales associated with the ARWA. The complexity associated with the extent and pattern of anthropogenic disturbances warrants the need for a simplification of these activities into a meaningful spatial context. Meaningful comparisons across the landscape should be valuable for setting restoration and reference areas by management personnel. The analysis of potential anthropogenic influences serves several purposes:

(1) To characterize the nature, extent, and potential influence of anthropogenic activities at each analysis scale;
(2) To portray the results in a simple, aesthetically appealing manner;
(3) To present a "likelihood" or "potential" for disturbance to aquatic, riparian or wetland environments based upon amount and distribution of an identified anthropogenic activity present in an individual watershed; and
(4) To provide a common framework to develop a comparative assessment of the watersheds or HUBs, not only associated with one administrative unit, but across several.

In order to satisfy these requirements, several procedural steps were involved:

(1) The ranking and percentile assignment of each HUB based upon that particular metric;
(2) The agglomeration of percentiles into four categories representing similar potentials for being influenced by anthropogenic activities;
(3) The cartographic representation of the analysis results; and
(4) The synthesis of the information into an additive effects analysis for the specific activity category (e.g., water use) as well as for all activities.

Ranking and Percentile Assignment

A geographic information system (GIS) analysis was performed to calculate dimensionless metrics within the individual hydrological unit boundaries (HUBs). For example, the number of stream diversions per stream mile, per 6th level HUB was identified as an appropriate and applicable metric. Thus, the total stream length (in miles) was calculated, the number of stream diversions was summarized, and the ratio of diversions to stream miles was calculated for each HUB (Table 5.4). After metric calculation, the HUBs are ranked by the metric's value, percentiles calculated, and then categorized by percentile value (Table 5.5). A rank of 1 was given to the highest metric value. The lowest rank was given to the HUB with the lowest metric value greater than zero. Those HUBs where the metric value equaled zero were not ranked. The percentile for each ranked HUB was then calculated. In order to simplify the results for display purposes and further analysis, all of the HUBs comprising the analysis scale were then divided into four categories. This procedure was used to provide another way of illustrating the relative amount of an activity across the landscape; obviously these ranks could be divided into more or less categories. Category 3 represented those HUBs whose percentile value was between 100 and 67%. Category 2 represented those HUBs whose percentile value was between 66% and 33%. Category 1 represented those HUBs whose percentile value was greater than zero, but less the 33%. Category 0 (not displayed on the table) was assigned to those HUBs where the value of the metric was equal to zero.

Table 5.4. Summary of GIS analysis related to the number of stream diversions per stream mile, per 6th level HUB.

6th Level HUB	Total Stream Length (mi)	Total # Diversions	# Diversions per Stream Mile
100800080403	65.83	0	0.000
100800080404	16.68	0	0.000
100800080405	23.42	0	0.000
100800080406	54.43	0	0.000
100800080502	48.45	0	0.000
100800080603	46.42	0	0.000
100800080604	50.68	0	0.000
100800080605	25.89	0	0.000
100800080606	47.79	0	0.000
100800100101	53.17	3	0.056
100800100102	34.69	0	0.000
100800100104	59.74	0	0.000
100800100105	34.84	0	0.000
100800100106	57.08	0	0.000
100800100107	29.88	0	0.000
100800100203	49.69	1	0.020
100800100204	32.15	2	0.062
100800100305	31.38	1	0.032
100800100307	39.50	0	0.000
100800100309	98.02	4	0.041
100800100401	35.45	1	0.028
100800100402	131.32	2	0.015
100800100601	47.73	0	0.000
100800100602	29.96	0	0.000
100800100603	24.27	0	0.000
100800100604	42.05	0	0.000
100800160102	69.73	0	0.000
100800160103	63.42	51	0.804
100800160104	39.00	0	0.000
100800160107	52.82	33	0.625
100800160108	41.52	10	0.241
100800160109	37.41	21	0.561
100800160301	41.91	8	0.191
100901010105	34.37	0	0.000
100901010106	89.33	4	0.045
100901010107	42.32	2	0.047
100901010109	30.53	0	0.000
100901010110	75.18	1	0.013
100901010203	52.25	5	0.096
100901010204	77.19	1	0.013
100901010205	83.58	3	0.036
100901010206	47.07	7	0.149
100901010207	123.61	2	0.016
100901010209	86.42	2	0.023
100902010301	64.18	1	0.016
100902050101	42.54	0	0.000
100902050102	71.95	6	0.083
100902050103	54.07	5	0.092
100902050106	42.35	0	0.000
100902050107	22.81	0	0.000
100902060104	21.34	0	0.000
100902060107	33.86	0	0.000
100902060201	41.89	0	0.000
100902060202	109.29	3	0.027
100902060302	33.23	2	0.060
100902060303	40.32	0	0.000
100902060304	36.98	1	0.027
100902060305	53.10	3	0.056
100800080401	33.65	0	0.000
100800080402	32.66	1	0.031
100800080601	24.09	0	0.000
100800080602	22.89	0	0.000
100800100103	26.14	0	0.000
100800160101	37.85	0	0.000
100901010101	34.90	0	0.000
100901010102	44.50	0	0.000
100901010103	44.75	0	0.000
100901010104	36.77	1	0.027
100901010201	22.27	4	0.180
100901010202	31.84	3	0.094
100902060101	34.17	0	0.000
100902060102	19.37	0	0.000
100902060103	22.63	0	0.000
100902060301	17.90	2	0.112

Table 5.5. Percentile determination and category assignment for the number of diversions per stream mile, per 6th level HUB metric.

Watershed ID	# Diversions per Stream Mile	Rank	%	Category
100800160103	0.804	1	1.00	3
100800160107	0.625	2	0.97	3
100800160109	0.561	3	0.94	3
100800160108	0.241	4	0.91	3
100800160301	0.191	5	0.88	3
100901010201	0.180	6	0.85	3
100901010206	0.149	7	0.82	3
100902060301	0.112	8	0.79	3
100901010203	0.096	9	0.76	3
100901010202	0.094	10	0.73	3
100902050103	0.092	11	0.70	3
100902050102	0.083	12	0.67	3
100800100204	0.062	13	0.64	2
100902060302	0.060	14	0.61	2
100902060305	0.056	15	0.58	2
100800100101	0.056	16	0.55	2
100901010107	0.047	17	0.52	2
100901010106	0.045	18	0.48	2
100800100309	0.041	19	0.45	2
100901010205	0.036	20	0.42	2
100800100305	0.032	21	0.39	2
100800080402	0.031	22	0.36	2
100800100401	0.028	23	0.33	2
100902060202	0.027	24	0.30	1
100901010104	0.027	25	0.27	1
100902060304	0.027	26	0.24	1
100901010209	0.023	27	0.21	1
100800100203	0.020	28	0.18	1
100901010207	0.016	29	0.15	1
100902010301	0.016	30	0.12	1
100800100402	0.015	31	0.09	1
100901010110	0.013	32	0.06	1
100901010204	0.013	33	0.03	1

These categories are meant to narrow the focus of management attention, in terms of potential areas influenced by an activity. Values that are considerably more or less than the general trends observed in the ranking process should be considered important for understanding elevated levels or uninfluenced areas. This analysis should be utilized by resource managers to prioritize further reach/site investigations and restoration efforts. The relative influence of an activity within a particular HUB compared to one throughout the assessment area should help focus efforts within the Forest and/or Grasslands. In addition, as other assessments are made throughout the Region new comparisons could be made at even larger scales.

Cartographic Representation of Results

Proper cartographic representation of the anthropogenic influence analyses greatly facilitates understanding, synthesis, and implementation of the results of the potential anthropogenic influence analysis. The inclusion of maps and graphs within the analysis discussion allows for the identification of spatial patterns and the distribution of potential anthropogenic influences, as well as insight into the statistical distribution of metric values within the analysis scale.

The production of the maps of the potential anthropogenic influence analysis chapter incorporated many cartographical standards. First, the maps must be friendly to a color-blind reader. To assist in the selection of the color schemes used in the maps, the website www.colorbrewer.org (2003) was utilized. This website provided an applet that assisted in the color scheme selection process. A second standard applied to the maps of this section was that the maps should have a consistent scale and spatial extent. A template for the creation of these maps was established using ESRI's ArcGIS software. In this manner, each map represents similar information in similar ways, thus reducing confusion in the interpretation of the cartographic product.

A third standard applied to the maps comprising the anthropogenic activities analysis is the inclusion of a graph depicting the statistical distribution of the metric value. A bar graph was utilized for this representation, with the metric value associated with the y-axis, and the rank of the HUB associated with the x-axis (Fig 5.4).

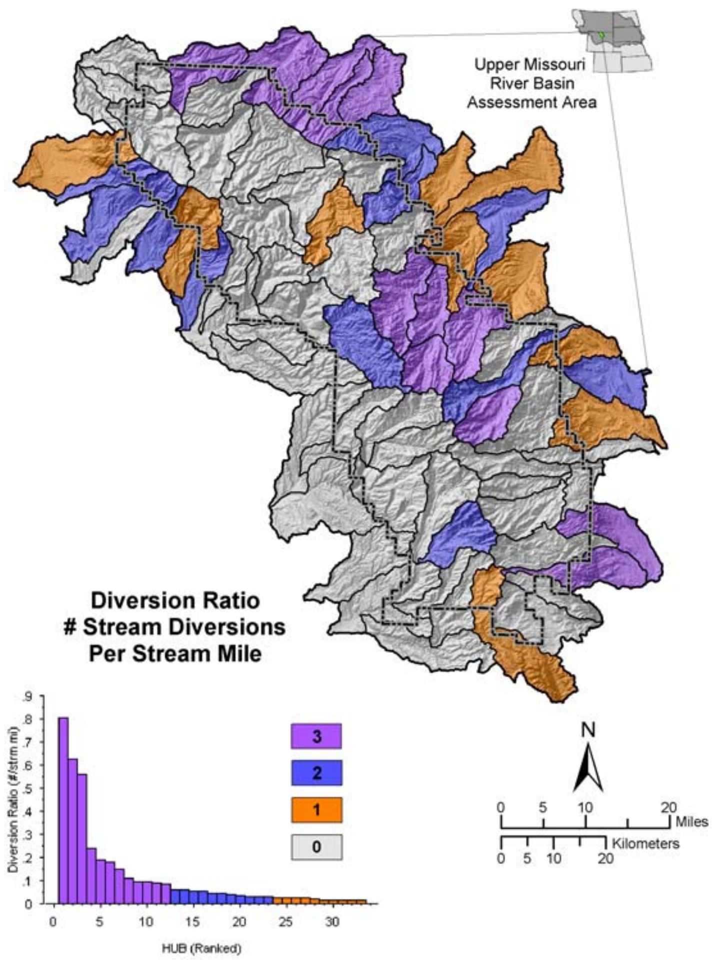


Figure 5.4. Cartographic standards applied to a map of a metric associated with the potential anthropogenic influence analysis.

A fourth cartographic standard applied to these maps was that of consistency. The font used, north arrow size and style, and scale bar are consistent on every map. The color schemes are identical for all maps in the anthropogenic analysis chapter. The color scheme used in each graph is consistent with that of the maps. Every graph in every map is of the same dimensions (2 inches by 3 inches) and had the same placement, resulting in a consistent "feel" on each map. An example of the map portraying the number of diversions per stream mile, per 6th level HUB illustrates the cartographic standards incorporated in the maps (Fig. 5.4).

<u>Additive Effects Analysis</u>

Analysis of the magnitude and distribution of individual anthropogenic activities throughout the analysis scales lends some insight into the potential influences upon aquatic, riparian, and wetland ecosystems. However, a more valuable analysis attempts to incorporate the potential effects associated with anthropogenic activities either as an activity category (e.g., water use), or as a whole (all of the 26 identified anthropogenic activities).

Activity Category Analysis

Analysis of each activity category included an additive ranking, as well as a cluster analysis. The purpose of the additive ranking analysis was to produce a value that qualifies an "overall likelihood" of a watershed being influenced by anthropogenic activities of a given category (e.g., the five metrics associated with water use). For each activity category, the category value of each metric was summed. The range of additive category values were then divided into quartiles (Table 5.6) and mapped using the previously discussed methods (Fig. 5.5).

An agglomerative cluster analysis based upon the metric values was also performed for each activity group. For this analysis, the actual metric values were summarized for each 6th level HUB. Prior to the cluster analysis, HUBs where no water-use activity was present were removed from the analysis, and assigned as cluster 0 because they had no data (e.g., information) to contribute. A Sorenson method, group average cluster analysis was performed on the remaining HUBs using PC-ORD2. The cluster analysis produced a dendrogram, from which clusters were identified (Fig. 5.6).

Table 5.6. Quartile breaks in additive ranking analysis.

Percentile	Quartile
0 - 25	1
26 - 50	2
51 - 75	3
76 - 100	4

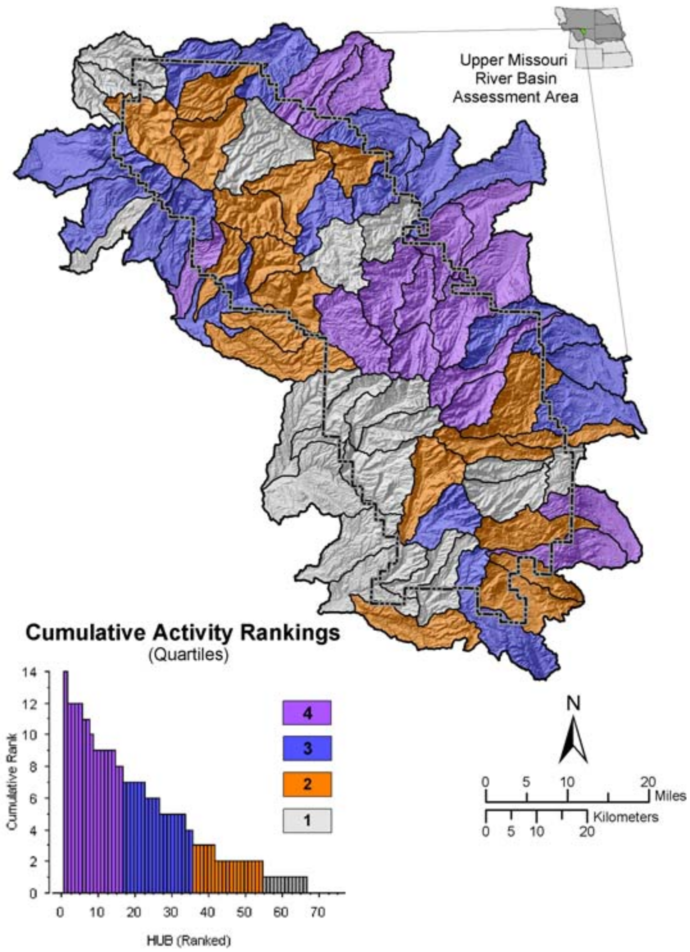


Figure 5.5. Additive ranking analysis results for the water use category.

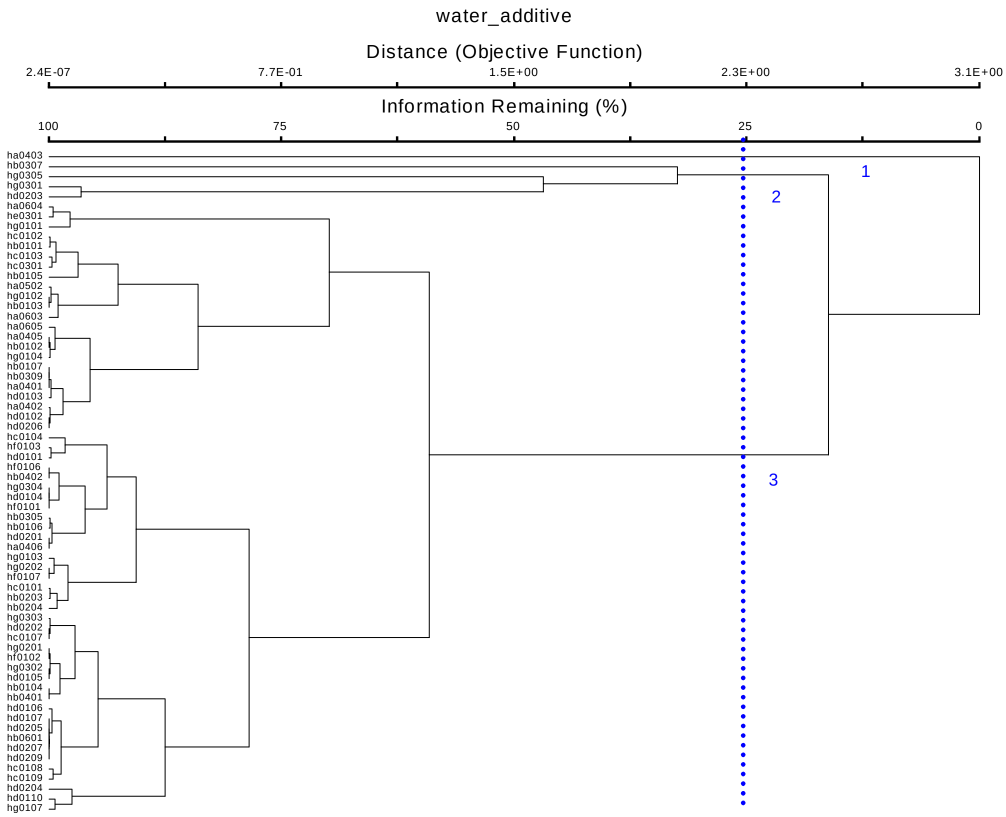


Figure 5.6.. Dendrogram identifying the results of the additive effects analysis of the water use category. Sixty of 74 6th level HUBS included in the analysis, the dashed vertical line denotes 25% information loss cutpoint, and numbers denote clusters.

The cluster groupings were then joined to the 6th level HUB coverage and mapped using the ARWA cartographic standards (Fig. 5.7). An analysis of variance analysis (ANOVA) was used to calculate an F-value useful in identifying the magnitude of differences in metric values between clusters (Table 5.7). A large f-value indicates that some clusters have a dramatically higher potential of being influenced by that particular metric than other clusters. The example given in Table 5.7 identifies a particularly large difference in the metric associated with the ratio of road length to stream length, while the number of road crossings per stream mile metric demonstrates little differences between clusters. In order to identify which cluster is most likely influenced, a scatterplot of the cluster means and standard deviations was produced for each metric (Fig. 5.8). In this example, it is likely that cluster 4 has a higher potential to be influenced by roads than clusters 0, 1, 2, and 3.

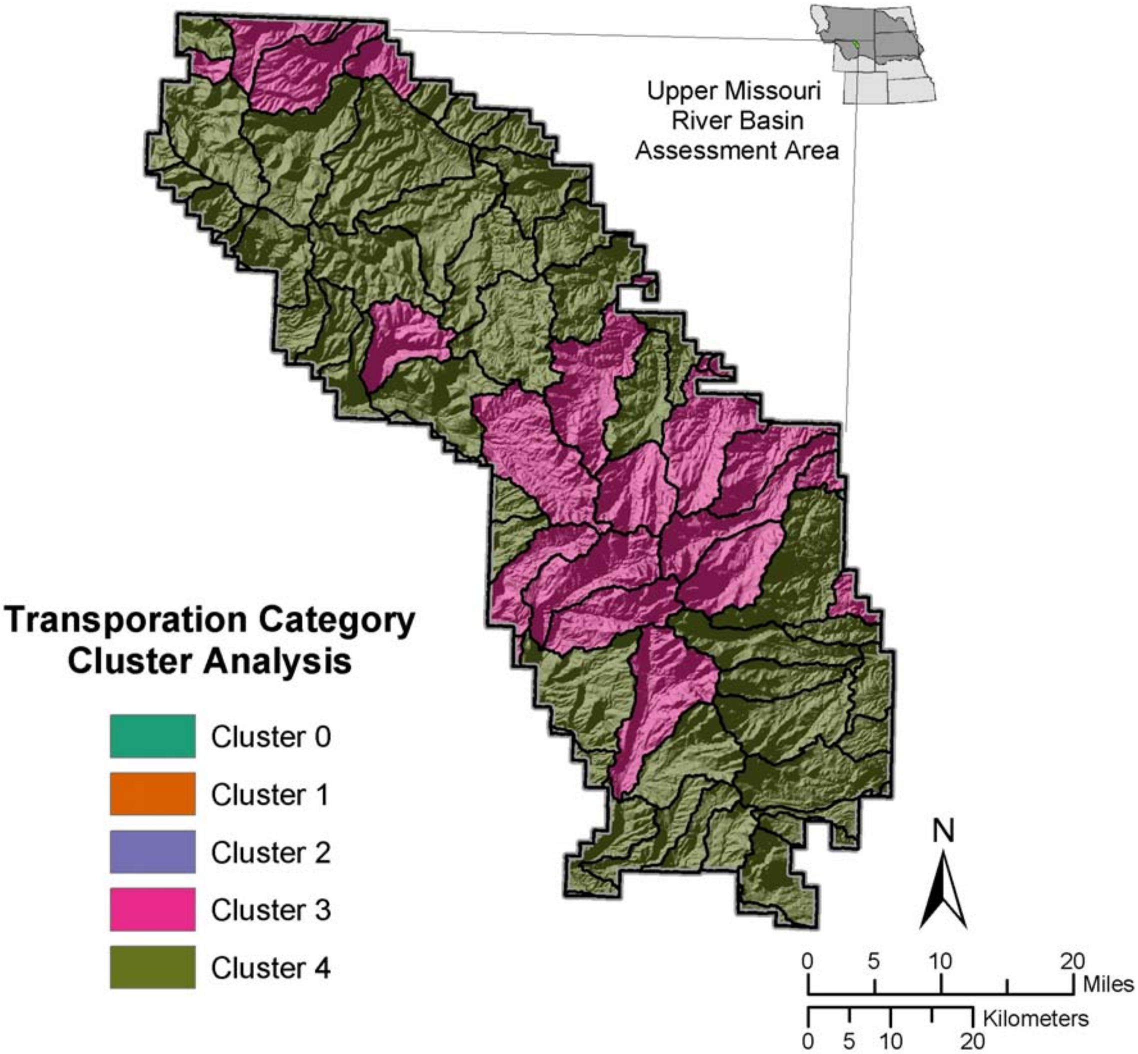


Figure 5.7. Cluster analysis results for transportation category.

Table 5.7. F-values for selected metrics of the transportation activity category.

Criteria	F Value
Length of Road (mi) per Total Stream Length, per 6th Level HUB	10.26
Number of Road Crossings per Stream Mile, per 6th Level HUB	0.83

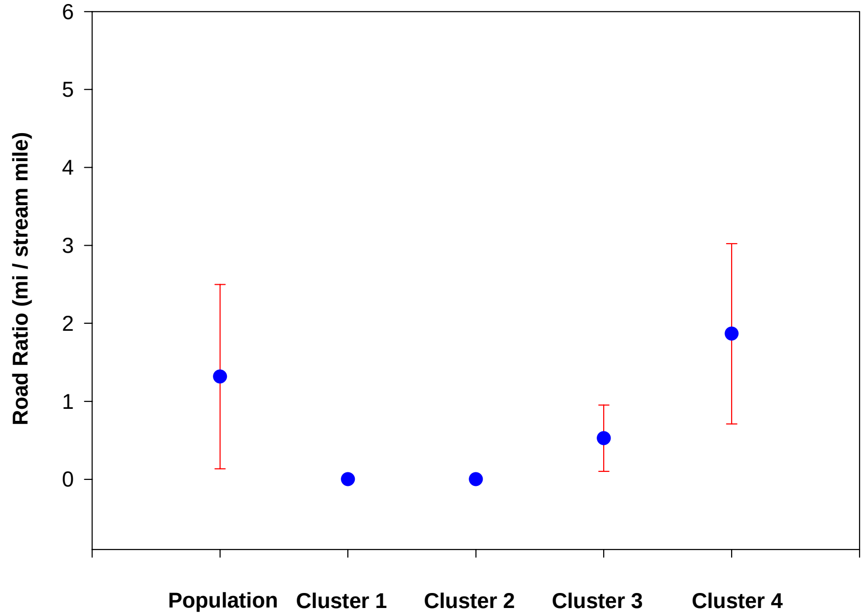


Figure 5.8. Road ratio: cluster means and standard deviations.

<u>All Activity Analysis</u>

Two analyses were used to identify the potential influences of all anthropogenic activities on aquatic, riparian, and wetland ecosystems. The activity category values for all identified anthropogenic activities were summed for each 6^{th} level HUB. Two analyses were performed on these cumulative values.

The first analysis attempts to characterize the overall potential influences that anthropogenic activities have upon riparian and wetland ecosystems at the management scale. The purpose of this analysis is to identify the degree to which riparian and wetland ecosystems may be influenced by anthropogenic activities throughout this scale. For this analysis, the category values for every identified anthropogenic activity were summed for each 6^{th} level HUB. It is assumed that the higher the cumulative category value, the greater the likelihood that the aquatic, riparian, and wetland resources in that particular HUB is influenced by anthropogenic activities. In order to provide increased utility, the cumulative values were divided into quartiles, allowing the reader to identify which HUBs are likely to be least, less, more, and most likely to be influenced by anthropogenic activities (Table 5.8). The quartiles were then mapped using the ARWA cartographic standards (Fig. 5.9).

Table 5.8. Quartiles and their cumulative percentile ranges and potential influence by anthropogenic activities.

Quartile	Percentile Range	Cumulative Percentile Value Range	Potential Influence
1	0 - 25	3 - 27	Least
2	25.1 - 50	28 - 33	Less
3	50.1 - 75	34 - 40	Moderate
4	75.1 - 100	41 - 58	High

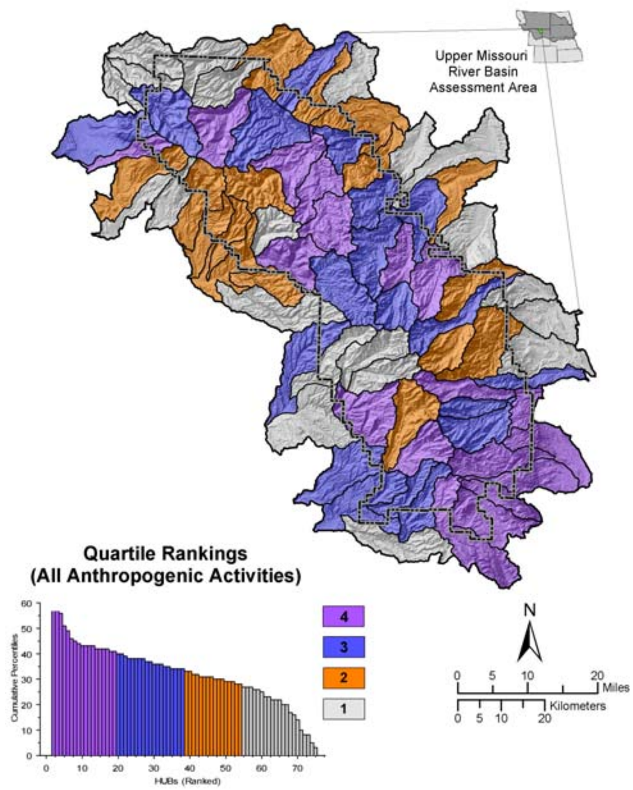


Figure 5.9. Cumulative percentile values grouped as quartiles.

The second analysis synthesizes the results of the first analysis with the results of the ecological driver cluster analysis for both riparian and wetland ecosystems. The purpose of this analysis is to identify how each ecological driver cluster may respond to the potential influences of anthropogenic activities. The distribution of cumulative category values was identified within each ecological driver cluster (Table 5.9). The cumulative values were divided into quartiles within each ecological driver cluster, and mapped using the ARWA cartographic standards (Fig. 5.10). The spatial distribution of cumulative category values and the potential effects of anthropogenic activities on HUBs comprising the cluster are discussed in a narrative assessment.

Table 5.9. Cumulative percentile values, ranks, and quartile designations for Wetland Cluster 1.

HUB ID	Subwatershed Name	Cumulative Percentile Value	Overall Rank	Rank w/in Wetland Cluster	Quartile
100901010202	Lower East Fork Big Goose Creek	58	1	1	4
100800080603	Paint Rock Creek-South Paint Rock Creek	43	9	2	4
100902060103	Seven Brothers Creek	43	10	3	4
100800080402	East Tensleep Creek	42	13	4	4
100902060101	South Clear Creek	39	21	5	3
100800100101	Shell Creek-Willett Creek	37	27	6	3
100902060102	Middle Clear Creek	36	30	8	3
100902060302	Kearny Creek	36	29	7	3
100901010201	Upper East Fork Big Goose Creek	34	35	10	3
100901010203	West Fork Big Goose Creek	34	34	9	3
100800080401	Upper Tensleep Creek	33	38	11	2
100902060301	South Piney Creek	31	42	12	2
100800080605	Upper Medicine Lodge Creek	27	54	13	1
100800080601	Paint Rock Creek-Trout Creek	26	57	14	1
100800080602	Long Park Creek	20	65	15	1

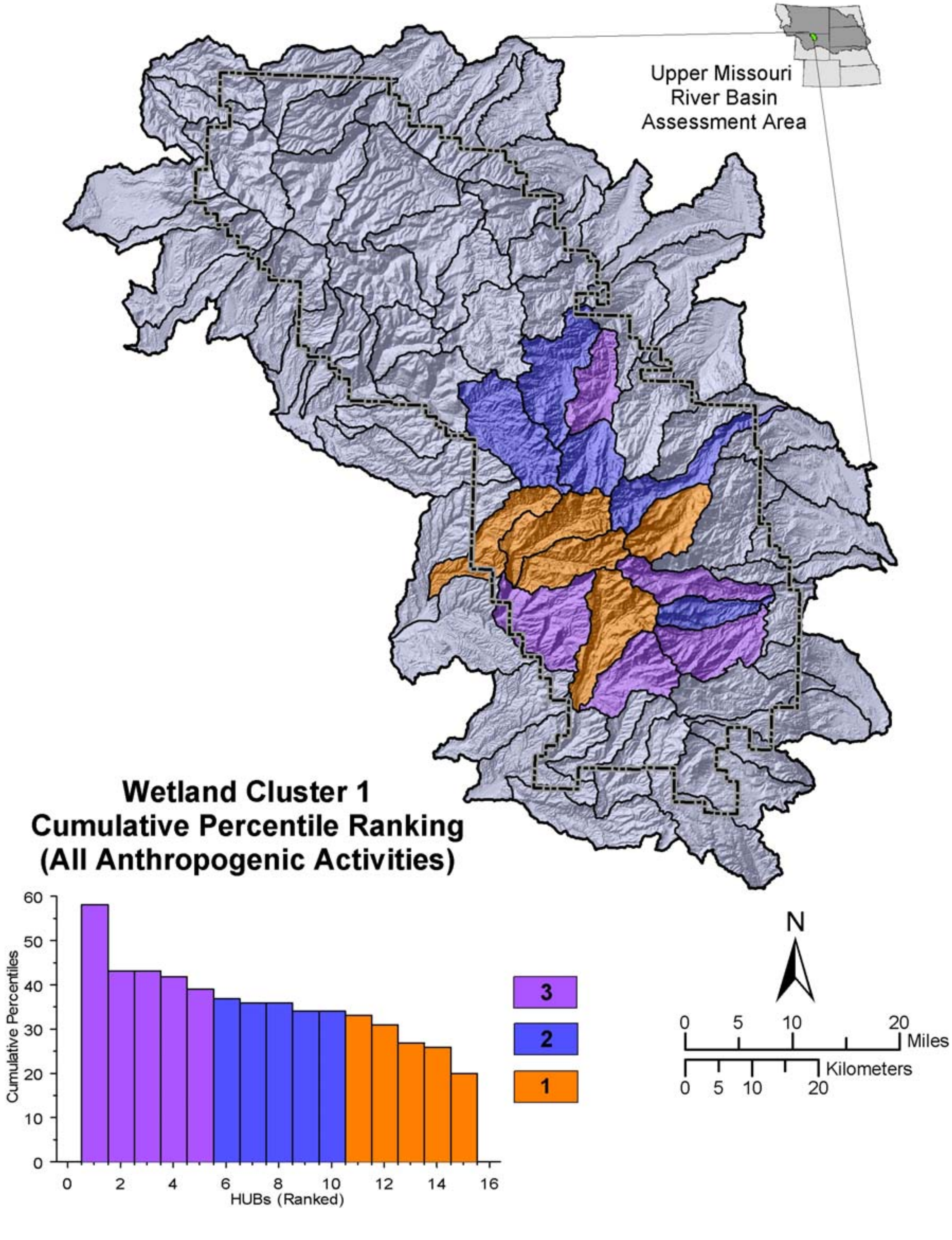


Figure 5.10. Wetland Cluster 1: cumulative percentile values.

CHAPTER 6
SYNTHESIS OF ECOLOGICAL DRIVER RESULTS AND ANTHROPOGENIC INFLUENCE ANALYSIS

While there is value in addressing the ecological driver and anthropogenic influence results separately, to fully realize the potential of the Aquatic, Riparian, and Wetland Assessment (ARWA), a synthesis of the relationship between the ecological driver process and the anthropogenic influences must be made (Fig. 6.1). This synthesis should only be made if all the steps involved in conducting the ecological driver and anthropogenic influences are complete.

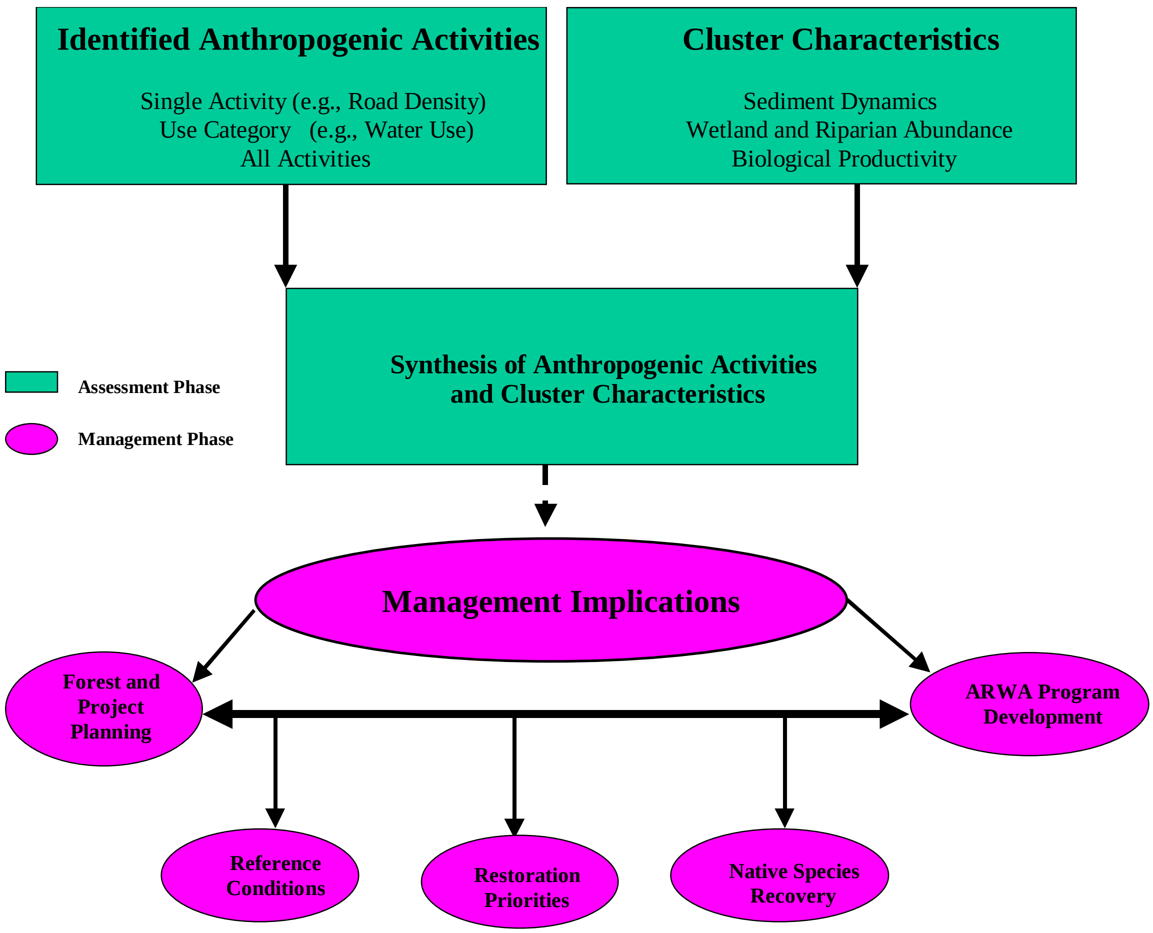


Figure 6.1. Relationship between anthropogenic activities, cluster analysis, and management implications addressed in the Aquatic, Riparian, and Wetland Assessment (ARWA)**.**

The first step in the synthesis portion of the analysis is to identify the importance of each resource value identified in Chapter 3. For example, we will use sediment transport as an important value that is influenced by anthropogenic activities and is addressed in the ecological driver analysis. For the purpose of this hypothetical example, we have identified four clusters that have various percentages of the ecological drivers used to address sensitivity to anthropogenic influences (Table 6.1). Our understanding of the sediment characteristics of the example assessment area shows that landscapes in steep topography, with non-calcareous geology (e.g., granitic bedrock), and within the rain and snow climatic zone are the most sensitive to sediment movement from anthropogenic activities (as well as natural disturbances).

Table 6.1. Hypothetical ecological driver results (percentages) for sediment transport dynamics. Bolded values represent the highest value for each cluster.

Clusters	High Gradient	Moderate Gradient	Low Gradient	Snow melt	Rain and Snow	Rain	Calcareous	Non-Calcareous
1	30	30	**40**	**60**	30	10	40	**60**
2	**80**	15	5	20	**75**	5	10	**90**
3	**60**	20	20	35	**50**	15	20	**80**
4	10	15	**75**	5	20	**75**	**90**	10

Based on these results, and knowledge of the hypothetical assessment landscape, educated decisions on the sensitivity to sediment movement can be made (Fig. 6.2). These results can be expressed in two ways, in relationship to another cluster (rank), and as a discrete value (low, medium, and high). These results should be valuable as a "risk assessment" for planning and project purposes. While these results are somewhat qualitative, they are based on a quantitative analysis of the ecological conditions that are the primary influence on sediment movement in the assessment area. As part of the validation process identified in Chapter 1, this assumption should be tested at the reach/site scale to have a better understanding of the relationships.

The next step in this process is to identify the particular cluster of HUBs with high sensitivity to sediment movement and identify the anthropogenic activities that are a concern from a sediment transport standpoint. For this example we will use road density and stream crossings. Table 6.2 illustrates the relative density of these two activities in the most sensitive cluster (cluster 2) in this landscape. Results of the anthropogenic analysis for these two activities reveals that there is a wide range of road and stream crossing densities in HUBs associated with this cluster.

Based on the example given above, there would be a logical way to prioritize 6th level HUBs for planning, project and program development. For instance, it would appear that aquatic, riparian, and wetland characteristics within HUB 5 would represent conditions in the absence of road development, while HUB 1 would represent watersheds with a relatively high influence. The aquatic, riparian, and wetland resources within these HUBs would be expected to have similar responses because they have similar ecological characteristics relative to sediment transport.

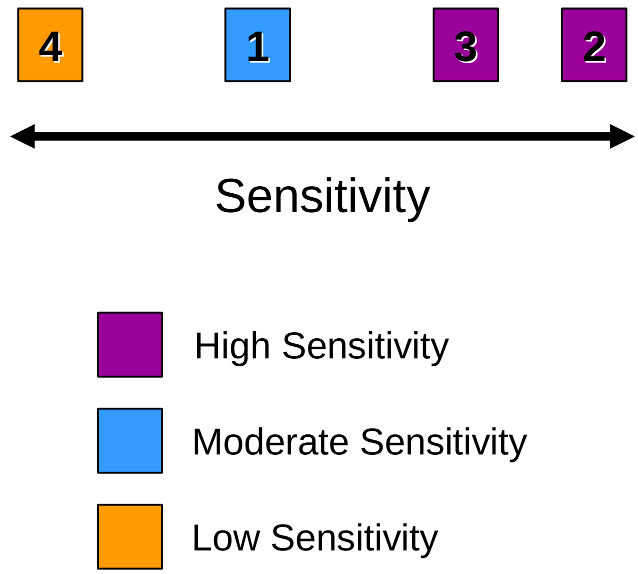


Figure 6.2. Hypothetical representation of ranking clusters (1 through 4) of 6th level HUBs based on sensitivity to sediment movement and characterizing them into sensitivity classes of high, medium, and low based on results of the cluster analysis.

Table 6.2. Hypothetical values of road density and stream crossings for HUBs within the sensitive cluster identified in Figure 6.1.

HUBS within Cluster 2	Road Density*	Stream Crossings**
1	8	10
2	4	6
3	3	2
4	1	1
5***	0	0

* - Measured as Miles within the Valley Bottom / Total Stream Mile / 6th Level HUB
** - Measured as Number of Crossings / Stream Mile / 6th Level HUB
*** - HUB located entirely in Wilderness Designated Area

At the reach/site scale, measurements of stream variables in similar channel types and position on the landscape could be used to validate the assumptions at the management scale illustrated above. For example, a measurement of stream pool habitat conditions could be used to determine the deviation from "reference conditions" identified in HUB 5 from Table 6.2 (Fig. 6.3). These results would illustrate an inverse relationship between road density and an important instream habitat variable (e.g., residual pool depth) for 6th level HUBs in an ecological cluster sensitive to sediment movement.

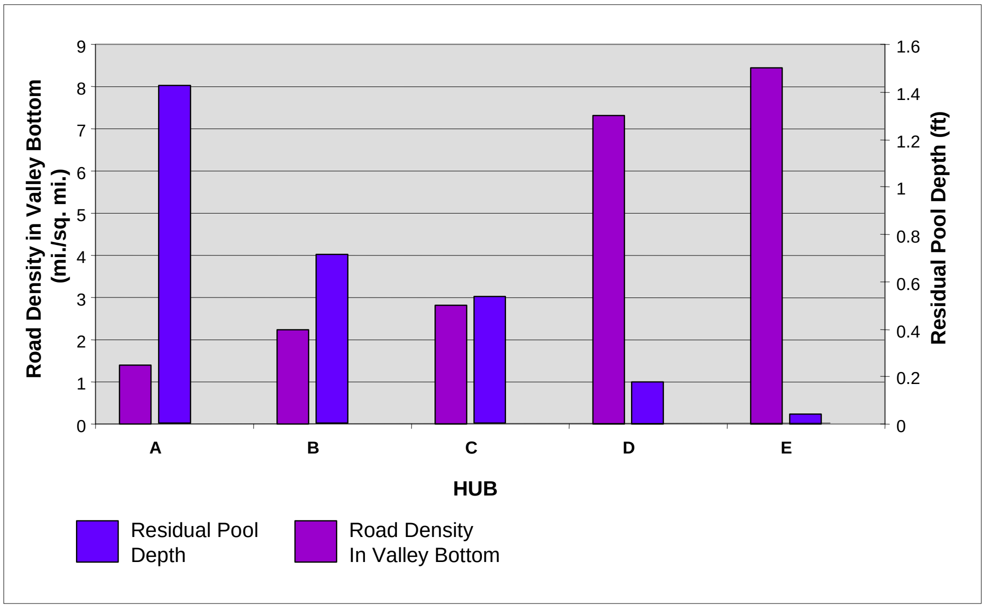


Figure 6.3. Hypothetical relationship between residual pool depths and road density for 6th level HUBs within the cluster sensitive to sediment movement.

Obviously, there are very few areas within Forest Service administered lands within Region 2 that are only influenced by one anthropogenic activity. Therefore this process can also be applied to the cumulative analysis results of groups of anthropogenic activities (e.g., water use) or for the analysis of all the activities that are located within the analysis area (see Chapter 5). Each of the processes used to address different combinations of anthropogenic activities are presented at the 6th level HUB resolution, as are the ecological driver analysis, so logical relationships can be made.

An important analysis that is beyond the scope of this assessment, but is directly related, is the relationship between the analysis explained above and species identified for management purposes. Figure 6.4 illustrates an example of how a particular inland cutthroat trout might be evaluated. In this hypothetical example an endemic cutthroat trout subspecies has been identified as being an important management target. It is understood that to ensure populations of this trout, adults inhabit pools with residual pool depths greater than 1.5 feet. Through the cluster analysis for this particular landscape it has been shown that a cluster of watersheds in particular is most conducive to this cutthroat's productivity (dominated by low stream gradients, calcareous geology, and rain and snow precipitation).

Anthropogenic analysis for this particular cluster reveals that road density is the primary activity that influences sedimentation in streams (Fig. 6.4). Further reach/site analysis reveals that indeed, there is an inverse relationship between road density and residual pools depths, further strengthening this assumption. While several 6th level HUBs contain adequate pool characteristics to support populations of this cutthroat, it is also apparent that there are several HUBs that should not be adequate because of limitations in pool depths and high road densities. Because the ecological driver analysis has shown that we would expect similar reach/site level characteristics for all these HUBs (given localized characteristics), we would also expect similar residual pool depth values.

In order to maintain current or restore potentially historic populations of this cutthroat trout, this information would be valuable to identify and prioritize currently acceptable road densities in HUBs where habitat criteria are being met and restoring HUBs where habitat is lacking. This of course does not mean remove all roads, but prioritize various maintenance and improvement opportunities as well as possibly some closures to move toward the conditions identified in the HUBs with less road densities.

It is apparent by these examples that the protocols identified in the ARWA documents are intended to be flexible and have utility in many different applications. By using quantitative information we reduce the need for subjective conclusions. However, when the need for subjectivity is needed, it can be supported with quantitative measurements. Assumptions associated with subjective conclusions can be validated through the process identified in Chapter 1, and the process adapted as necessary.

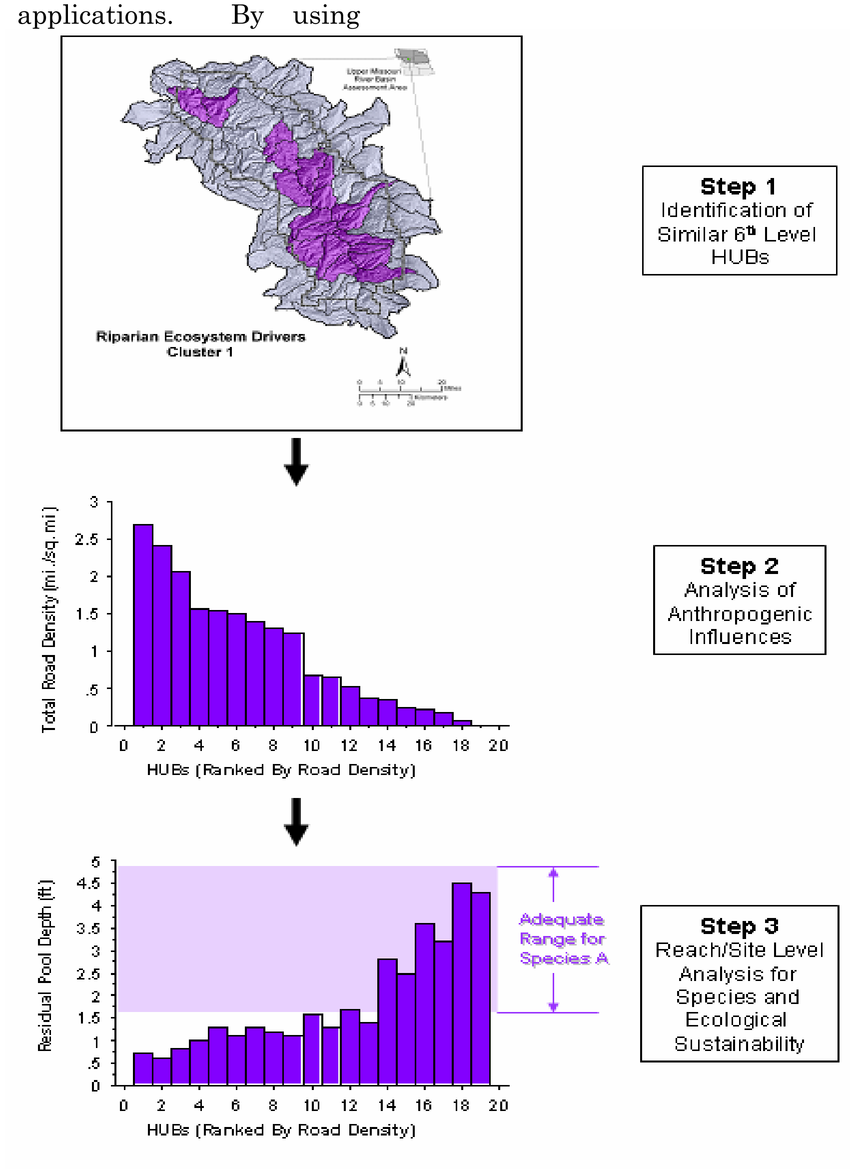


Figure 6.4. Hypothetical example of the relationship between a cluster of 6th level HUBs important for management of an endemic cutthroat trout, road densities, and their relationship to residual pool depths. The final step is identifying the habitat needs of the cutthroat trout subspecies and the habitat conditions present. These results indicate that elevated road densities ultimate have a detrimental effect on cutthroat trout populations through habitat reduction. Priorities for road management can now be made to achieve desired conditions.

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GLOSSARY

abiotic:
The nonliving factors in the environment including climactic, geological, and geographical features that may influence ecological systems.

adaptive management:
A type of natural resource management that implies making decisions as part of an on-going process. Monitoring the results of actions will provide a flow of information that may indicate the need to change a course of action. Scientific finding and the needs of society may also indicate the need to adapt resource management to new information.

aggradation:
The process by which a stream's gradient steepens due to increased deposition of sediment.

algivorous:
Feeding on algae.

allochthonous:
Derived from outside a system, such as leaves of terrestrial plants that fall into a stream.

allotment (range allotment):
The area designated for use by a prescribed number of livestock for a prescribed period of time. Though an entire Ranger District may be divided into allotments, all land will not be grazed, because other uses, such as recreation or tree plantings, may be more important at a given time.

anadromous:
Ascending, especially of fish that ascend rivers to spawn.

anthropogenic:
An action by humans that influences species or ecosystem form, function or population dynamics.

antidunes:
Bedforms that form in fast shallow flows.

aquatic ecosystem:
Waters of the United States, including wetlands, that serve as habitat for interrelated and interacting communities and populations of plants and animals. The stream channel, lake or estuary bed, water, biotic communities, and the habitat features that occur therein.

ARWA:
Aquatic, riparian, and wetland assessment.

austral limits
The southern or southerly extent.

autochthonous:
Any indigenous animal or plant.

autotrophism:
Literally, self-feeding, a method of obtaining nutrients in which the principle carbon source is inorganic, usually carbon dioxide. Organic materials are then synthesized using light energy or chemical energy. In the case of chemical energy, it is derived from the oxidation of an inorganic compound. Autotrophs are important ecologically as the primary producers of organic carbon for all heterotrophic organisms.

avulsion:
A separation by force. The sudden removal of a person's land by the action of water, as by flood or change in the course of a stream, without a resulting loss of ownership.

bedform:
The shape of the surface of a bed of granular sediment produced by the flow of air or water over the sediment. The nature of the bedform depends upon the flow strength and depth, and upon sediment grain size. For fine to medium sand, the typical sequence of bedforms produced under conditions of constant depth and increasing strength of unidirectional flow is: no movement; ripples; sand; waves; dunes; and an upper-flow-regime plane bed. In coarse sand a lower-flow-regime plane bed develops first, then ripples, followed by sand waves, then dunes, and an upper-flow-regime plane bed. At higher-strength flows, the upper flow regime plane bed is replaced by antidunes.

bedload:
Material moving on or near the stream bed by rolling, sliding, and sometimes making brief excursions into the flow a few diameters above the bed.

benthos:
Animals and plants living on or within the substrate of a water body (freshwater, estuarine, or marine).

biodiversity or biological diversity:
The number and abundance of species found within a common environment. This includes the variety of genes, species, ecosystems, and the ecological processes that connect everything in a common environment.

biogeography:
Study of geographical distribution of plants and animals.

biota:

All living things existing within a given area or on the Earth.

buffer:
A land area that is designated to block or absorb unwanted impacts to the area beyond the buffer. Buffer strips along a trail could block views that may be undesirable. Buffers may be set a side next to wildlife habitat to reduce abrupt change to the habitat.

cascade:
Habitat type characterized by swift current, exposed rocks and boulders, high gradient, and considerable turbulence and surface agitation, and consisting of a stepped series of drops.

clasts:
A rock particle or fragment.

clear cut:
A harvest in which all or almost all of the trees are removed in once cutting.

cover type (forest cover type):
Stands or a particular vegetation type that are composed of similar species. The aspen cover type contains plants distinct from the pinyon-juniper cover type.

conservation strategies:
Documented strategies developed to provide for the long-term sustainability of taxa and ecosystems. Typically taxa or ecosystems that are rare of at-risk of becoming extinct in the foreseeable future.

DCA:
Detrended correspondence analysis.

dendrogram:
A diagram, similar to a family tree, that indicates some type of similarity between different organisms.

detrital:
Loose natural material that results from the direct disintegration of rocks or organisms, often a mixture of the two.

detritivorous:
Feeding on detritus.

developed recreation:
Recreation that requires facilities that, in turn, result in concentrated use of the area. For example, skiing requires ski lifts, parking lots, buildings, and roads. Campgrounds require roads, picnic tables, and toilet facilities.

dispersed recreation:
Recreation that does not occur in a developed recreation site, such as hunting, backpacking, and scenic driving.

ecological drivers:
Environmental factors that exert a major influence on the fitness of individuals and species population size. These drivers can be considered as comprising the physico-chemical template of an ecosystem and the dominant expression of these drivers at a particular spatial scale influences the relative success of species and thus community composition at that scale.

ecological integrity:
Refers to an ecosystem that will function successfully and optimally under conditions characteristic of the locale. In addition to including optimal levels of energy flow, an ecosystem of high integrity should maintain a balanced, adaptive community having species composition, biodiversity, and functional processes naturally characteristic of the area. Ecological integrity also assumes an ecosystem's ability to withstand stress or exhibit resilience in the face of unexpected future perturbations to environmental conditions. It is also simply the maintenance of the community structure and function characteristics deemed satisfactory to society. The attributes of an ecosystem with integrity are inherently qualitative rather than absolute, but generally include ecosystem health, biodiversity, stability, sustainability, naturalness, wildness, and beauty.

ecoregions:
A general description of the ecosystem geography of the nation with areas designated as domains, divisions, and provinces.

ectothermic:
Animals that lack an internal system for body temperature regulation, thus tend toward the temperature of their environment. They have evolved a wide array of behavioral mechanisms that enable them to control their temperature by using environmental cooling and heating. This situation is found in most animals other than birds and mammals. They have been called "cold-blooded" because their body temperature is often, though not always, cool relative to endotherms.

endemic:
Species restricted to a particular geographic area; for aquatic species, usually limited to one or a few small streams or a single drainage.

eutrophic:
Condition of a lake or pond where deleterious effects are caused by increased nutrients (nitrogen and phosphorous) and a decrease in oxygen. *Eutrophication* is a process whereby fresh water becomes enriched in nutrients, thus beginning the cycle of ecological succession. When this happens as a result of sewage or fertilizer runoff, the concentrated over stimulation of algal growth results in a bloom. When the excess dead algae are decomposed by aerobic bacteria at an abnormally high rate, oxygen is depleted from the water, causing aquatic animals such as fish to die of suffocation.

evapotranspiration:
The rate of liquid water transformation to vapor from open water, bare soil, or vegetation with soil beneath.

extirpation:
Extinction of a species from all or part of its range.

fragmentation:
The splitting or isolating of patches of similar habitat but including other types of habitat. Habitat can be fragmented naturally or from management activities, such as road culvert construction.

geochemistry:
Study of the chemical composition of the earth's crust.

geomorphic:
Pertaining to or like the form or figure of the earth. Geomorphology is the study of form, nature, and evolution on earth's surface.

GIS:
Geographic Information Systems.

groundwater:
Generally all subsurface water as distinct from surface water; specifically, that part of the subsurface water in the saturated zone (a zone in which all voids are filled with water) where the water is under pressure greater than atmospheric.

heterotrophic:
A method of obtaining nutrients by feeding on other organisms. Heterotrophic organisms are *chemotrophic*, obtaining both their energy and carbon atoms by degrading ingested organic compounds. At least 95% of the organisms on earth (all animals, all fungi, and most bacteria and protests) live by feeding on the chemical energy fixed into carbon compounds by photosynthesis.

hierarchical classification:
A classification technique in which each, more detailed level, falls within the delineation of the next higher level class. Predictable and repeatable properties of a given level in the classification are defined by the next higher level.

historic range of variability (HRV):
Spatial and temporal variation in various ecosystem characteristics when the influences of Euro-Americans were minimal (1600-1890).

HUB:
Hydrologic unit boundaries as part of the development of a National Watershed Boundary Dataset that will replace HUCs.

HUC:
Hydrologic unit codes. Code cataloguing the watershed, developed by USGS.

hydroclimatology:
The geology of groundwater, with particular emphasis on the chemistry and movement of water.

hydrogeology::
The geology of groundwater, with particular emphasis on the chemistry and movement of water.

hyporheic zone:
The layer of stream channel substrate extending as deep as there is interstitial flow.

hypsometry:
The measurement of elevation relative to sea level.

in-situ:
Literally, "in place" or in original position.

lentic:
An environment created by standing water for instance lakes, ponds, and permanent or temporary pools.

lithology:
Description or study of the outermost solid layers of the earth.

lotic:
Environments formed by running water, such as streams and rivers.

mesotrophic:
This term is applied to clear water lakes and ponds with beds of submerged aquatic plants and medium levels of nutrients.

montane:
A cool, moist ecological zone usually located near the timberline and usually dominated by evergreen trees.

multiple scale assessment:
Assessments that evaluate the appropriate species and/or ecological characteristics and influences at more than one appropriate scale. Typically, the scales are hierarchical so reference can be made between scales.

NEPA:
National Environmental Policy Act.

NFMA:
National Forest Management Act.

NHD:
National Hydrography Dataset.

NRIS:
National Resource Information System.

NWI:
National Wetland Inventory.

old growth:
Old forests often containing several canopy layers, variety in tree sizes, species, decadent old trees, and standing and dead woody material.

oligotrophic:
Lakes that are deficient in nutrients and consequently low in productivity.

overbank deposit:
Sediments (usually clay, silt, and fine sand) deposited on flood plain by river overflowing banks.

peatlands:
Contain partially reduced plant or wood material, containing approximately 60 percent carbon and 30 percent oxygen. An intermediate material in process of coal formation.

physiography:
Physical geography; topography description of natural phenomena.

plankton:
An ecological designation for various microscopic aquatic organisms that drift more or less freely in the upper regions of a water body.

palustrine:
Comes from the Latin word "palus" or marsh. Wetlands within this category include inland marshes and swamps as well as bogs, fens, tundra and floodplains. Palustrine systems include any inland wetland which lacks flowing water and contains ocean derived salts in concentrations of less than .05%.

physico-chemical:
Pertaining to both physical and chemical properties, changes, and reactions.

plane bed:
A near-horizontal surface of sand or gravel. Two types of plane bed are found. Upper-stage plane beds are produced by the intense transport of sediment by high-velocity, shallow flows (upper-flow-regime conditions), and characterized by primary current lineation on the sediment surface. Lower-stage plane beds are produced only in coarse sands and gravels by flow conditions broadly similar to those which generate current ripples in finer sand. The lower-stage plane bed exhibits a series of shallow scours on the sediment surface. The accumulation of plane-bedded sediment gives rise to an internal sedimentary structure of horizontal lamination.

plankton:
The assemblage of microscopic organisms, (zooplankton), that drift passively in the surface waters of seas and fresh water. Their location is mainly dependent on currents and water clarity, as the plants require sunlight for photosynthesis. The diatoms, tiny algae, and small animals drift freely; larger animals swim independently. Plankton is the basis of all aquatic food-chains.

pool:
A portion of the stream with reduced current velocity, often with water deeper than the surrounding areas; frequently usable by fish for resting and cover. Or a small body of standing water, e.g., in a marsh or on the flood plain.

pool-riffle:
The alternating sequence of deep pools and shallow riffles along the relatively straight course of a river. The distance between the pools is 5-7 times the channel width.

refugia:
Small isolated areas where extensive changes, most typically due to changing climate, have not occurred. Plants and animals formerly characteristic of the region in general now find a refuge from the new unfavorable conditions in these areas. An example might be a mountain summit projecting above a glaciated lowland region.

regolith:
The irregular blanket of loose, noncemented rock particles that cover the Earth.

resilience:
The ability of an ecosystem to maintain diversity, integrity, and ecological processes following a disturbane.

riffle:
A shallow rapid where the water flows swiftly over completely or partly submerged obstructions to produce surface agitation, but standing waves are absent.

riparian:
Pertaining to anything connected with or immediately adjacent to the banks of a stream or other body of water.

riparian ecosystem:
The ecosystems around or next to water areas that support unique vegetation and animal communities as a result of the influence of water.

river continuum:
Gradual changes in the biological community of a river as energy sources and physical conditions change from headwaters to lowlands.

riverine system:
All wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens; and (2) habitats with water contining ocean derived salts in excess of 0.5 percent.

scale:
In ecosystem management, it refers to the degree of resolution at which ecosystems are observed and measured.

salmonids:
Fish of the family Salmonidae, the chars, trouts, salmons, and whitefishes.

sensitive species:
Plant or animal species, which are susceptible to habitat changes or impact from activities. The official designation is made by the USDA Forest Service at the Regional level and is not part of the designation of Threatened or Endangered Species made by the US Fish and Wildlife Service.

seral:
The stage of succession of a plant or animal community that is transitional. If left alone, the seral stage will give way to another plant or animal community that represents a further stage of succession.

silivicultural system:
The cultivation of forests; the result is a forest of a distinct form. Silivicultural systems are classified according to harvest and regeneration methods and the type of forest that results.

siliviculture:
The art and science that promotes that growth of single trees and the forest as a biological unit.

snag:
A standing dead tree. Snags are important as habitat for a variety of wildlife species and their prey.

species conservation project:
Designed to incorporate terrestrial and aquatic ecosystem assessments, species assessments, reference models, and species conservation strategies into an overall framework that will ensure a thorough evaluation of species viability. The assessments will serve planning by providing a strong science base from which to build plant alternatives without directing management. The SCP is designed to provide a regionally consistent set of information to identify species at risk and to provide for their viability.

stand:
A group of trees that occupies a specific area and is similar in species, age, and condition.

sustainability:
The ability to sustain ecological integrity over the long term, and leave the task of evaluating sustainability to the forest managers, who must do so within the context of their actions.

sustainable:
The yield of a natural resource that can be produced continually at a given intensity of management is said to be sustainable.

taxon:
The members of a particular taxonomic group such as a *class, family*, or *genus*. The members of the class *Mammalia* form a taxon. taxa (pl).

trophic level:
One of a succession of steps in the movement of energy and matter through a food chain in an ecosystem. Organisms are considered to occupy the same trophic level when the matter and energy they contain have passes through the same number of steps since their entrance by way of photosynthesis or chemosynthesis.

USFS:
United States Forest Service.

viable population:
The number of individuals of a species sufficient to ensure the long-term existence of the species in natural, self-sustaining populations that are adequately distributed throughout their range.

watershed:
The total area above a given point on a stream that contributes water to the flow at that point. Drainage basin, catchment basin, or river basin.

WBD:
National Watershed Boundary Dataset.

wetlands:
The biome consisting of freshwater swamps, marshes, bogs, ephemeral ponds, and saltwater marshes. They are characterized by continual or seasonal standing water, which creates a specialized soil environment with very little oxygen, retarding decay. Although wetlands occupy only a small portion of Earth's land area, the organisms that have adapted to this environment are very specialized and perform important functions in the environment.

zoogeography:
Study of geographic distribution of animals.