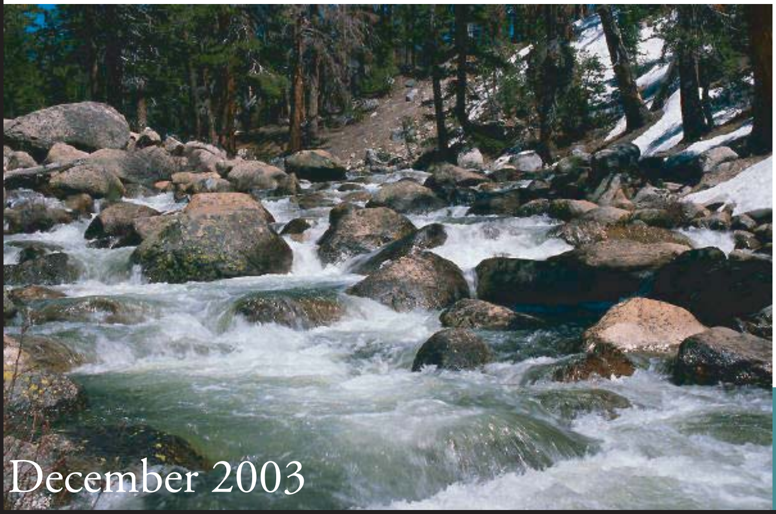
Watershed Analysis and Management (WAM) Guide for States and Communities



December 2003

EPA Watershed Analysis and Management Project

Foreword

Using a watershed approach provides a unique and effective way to assess the environment, identify problems, establish priorities for preservation or restoration, and implement solutions. The Watershed Analysis and Management (WAM) Program is an effort to guide communities in the successful application of a watershed approach and led to the development in 2002 of this *Watershed Analysis and Management (WAM) Guide for States and Communities*.

The Environmental Protection Agency's (EPA) Office of Wetlands, Oceans, and Watersheds (OWOW) and the American Indian Environmental Office (AIEO) collaborated in 1997 on a joint project to develop a comprehensive WAM methodology. The initial WAM approach was based on watershed planning efforts in the Pacific Northwest, including the Washington State watershed analysis methodology for state and private forest lands and the Northwest Forest Plan watershed analysis guide for federal ownership. The concept was to extend existing capabilities to address a nationwide range of ecological environments, project objectives, and watershed management issues at the state, community, and tribal levels. With substantial support from the AIEO, a more comprehensive approach was undertaken to include the additional issues of tribal cultural and community values. The first product, *Watershed Analysis and Management (WAM) Guide for Tribes*, was developed with a system development grant from OWOW to the Pacific Watershed Institute, concurrent with pilot applications of the approach, through AIEO grants, by tribes representing different ecological environments, objectives, and community issues.

The *Watershed Analysis and Management (WAM) Guide for Tribes* was published in September 2000. In addition, tribal WAM field training was developed and implemented with the White Mountain Apache team, with the *WAM Field Course Training Guidance* produced in 2001. A related effort, using a watershed approach to Total Maximum Daily Loads (TMDLs), was undertaken with the Navajo Nation in Window Rock, Arizona, and the guide *Internal Capacity Building for Tribal TMDLs* was produced in 2002. Simultaneously, the WAM process was applied to state and community projects, including development of a *Watershed Quality Management Plan*. This plan serves as a template for incorporating quality assurance into other watershed plans and documents.

The *Watershed Analysis and Management (WAM) Guide for States and Communities* has been strengthened by application of the WAM process in watersheds across the United States. The guide incorporates knowledge gained through recent applications of the WAM process to a large-scale county watershed project in Ohio and to a tri-county coalition watershed project in the Snohomish River basin in Washington State. Examples from these projects are included in the guide.

The WAM program has benefited from major program support and technical contributions from OWOW and AIEO; Dave Somers, President, Pacific Watershed Institute; Steve Toth, consultant and a principal contributor to both the *Watershed Analysis and Management (WAM) Guide for Tribes* and the *Watershed Analysis and Management (WAM) Guide for States and Communities*; the tribal pilot leads, Tammis Coffin, Latane Donelin, Jonathan Long, and John Sims; and Paul Braasch, Environmental Coordinator, Clermont County, Ohio, whose inputs made major contributions to this document.

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This guide is patterned after a number of watershed analysis methods developed in the Pacific Northwest. These efforts to promote watershed analysis have been an invaluable source of information for this guide and include the Washington State methodology developed for the Washington Forest Practices Board, the Federal guide for watershed analysis produced by the Regional Ecosystem Office, and the Oregon watershed assessment manual created for the Governor's Watershed Enhancement Board.

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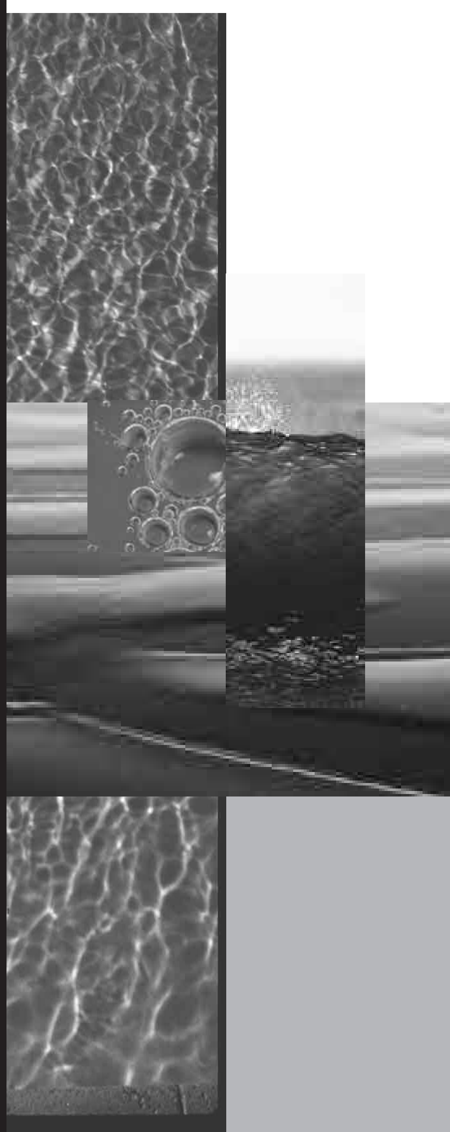


Acronym List

BIA	Bureau of Indian Affairs
BOD	Biochemical oxygen demand
BLM	Bureau of Land Management
BMP	Best management practice
cfs	cubic feet per second
CWA	Clean Water Act
DO	Dissolved oxygen
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
HUC	Hydrologic Unit Code
IAC	Intergovernmental Advisory Committee
IFIM	Instream Flow Incremental Methodology
NCASI	National Council of the Paper Industry for Air and Stream Improvement
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	U.S. Department of Agriculture Natural Resources Conservation Service
NWI	National Wetland Inventory
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
QA/QC	Quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
RIEC	Regional Interagency Executive Committee
RUSLE	Revised Universal Soil Loss Equation
SCS	U.S. Department of Agriculture Soil Conservation Service
TIA	Total impervious area
TMDL	Total Maximum Daily Load
TSS	Total suspended solids
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USDI	U.S. Department of the Interior
USFS	U.S. Department of Agriculture Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WAM	Watershed Analysis and Management
WEPP	Water Erosion Prediction Procedure
WFPB	Washington Forest Practices Board

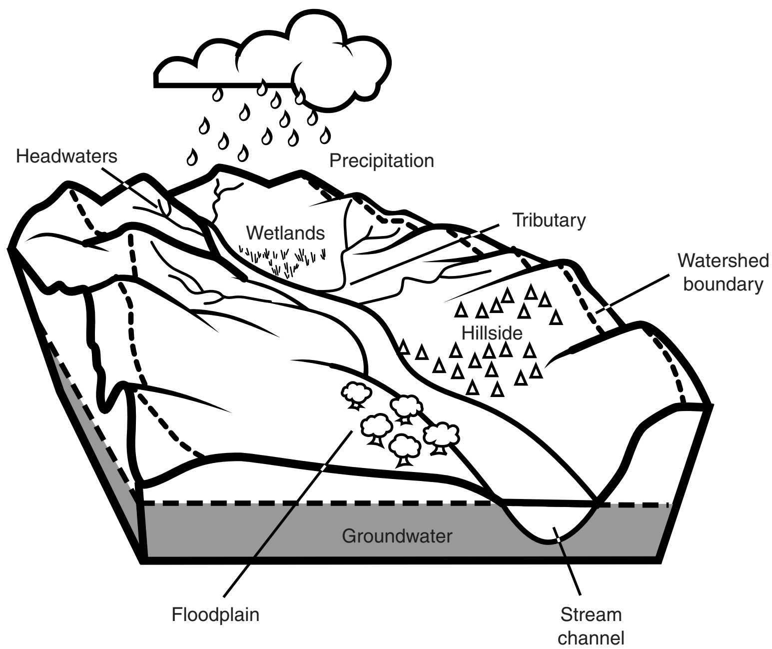
Introduction

The rivers, lakes, estuaries, and wetlands in our communities are among our most precious resources. We depend on them for clean water to drink, to irrigate crops, to run industries, to support fish and wildlife, and to recreate with our families. Yet, today most of the Nation's major watersheds have serious water quality and habitat-related problems.

Traditionally, management of water resources has focused on individual components of the environment, such as drinking water protection, water quality analysis, or wetland preservation. Sources of pollution are also typically evaluated on a site-by-site basis. Millions of dollars are spent to evaluate aquatic resources, conduct monitoring programs, and develop restoration plans, yet these projects are rarely considered collectively. Unfortunately, the health of many watersheds continues to decline as a result of the cumulative impacts from multiple land uses.

To address natural resource issues more comprehensively, a watershed approach can be used to address problems across administrative and political boundaries (Figure 1). The watershed approach emphasizes partnerships between communities and government agencies. This coordination allows for the integration of community values with scientific information about watershed conditions. Successful watershed partnerships lead to effective programs for improving water quality and restoring aquatic resources.

Figure 1. A watershed approach focuses on addressing water resource issues by river basins



While each watershed partnership must address a unique set of social and environmental issues, certain elements exist that are common to successful watershed partnerships. The Watershed Analysis and Management (WAM) approach outlined in this guide describes these common elements in the form of practical methods, tools, and examples that can help ensure effective and efficient partnerships (Box 1).

Box 1. What is WAM?

The WAM process is a well-defined, yet flexible method to credibly examine and develop solutions to watershed problems.

The WAM process can be used by any organization or partnership to help define goals and develop strategies for improving watershed conditions (Box 2). The WAM process encourages the involvement of broad community

Box 2. WAM objectives

- Characterize current and historical watershed conditions
- Evaluate the cumulative effects of land management
- Improve protection of community resources
- Promote management options that protect watershed resources
- Develop effective restoration projects
- Design watershed-specific monitoring programs

interests, including landowners, businesses, government agencies, tribes, and other local groups. The WAM guide provides ideas and tools for developing community involvement and improving communication.

The WAM guide also describes practical methods for using scientific information to credibly assess watershed conditions. WAM encourages an ecosystem approach through the integration of different scientific disciplines. The WAM approach also emphasizes the use of existing information such as maps, photographs, monitoring data, and environmental reports as the basis for planning efforts. Combining modern watershed assessment techniques with the local knowledge and experience of community members produces valuable insights about historical conditions, resource trends, and restoration opportunities. Communities can use this information to develop practical management solutions that protect and restore their important resources.

WAM is a flexible process that can be adapted to address a broad range of local issues and watershed conditions (Box 3). WAM can also incorporate and enhance existing environmental programs to use funds and personnel most efficiently. The tools provided in the WAM process can be used in any watershed to help ensure that high quality information is collected to support practical projects that will effectively improve the health of the ecosystem.

Box 3. WAM for novice and expert watershed groups

The WAM guide provides tools to help ensure effective watershed improvements. Communities that are just beginning a watershed approach to restoration can use WAM to help organize their activities, define clear goals, and develop a strategy to achieve those goals. The five-step process provides a road map for addressing varied watershed issues and ensuring a long-term and effective watershed improvement strategy. The technical assessment modules provide a “cookbook” approach to help assemble readily available information important to assessing and evaluating watershed conditions.

More experienced watershed groups may benefit from the examples and strategies used by other watershed groups around the country. The WAM framework may also be a helpful way to organize disparate watershed efforts and communicate watershed objectives. It may also help to create a more interdisciplinary and holistic approach to addressing watershed issues.

Watershed management is a long-term process that requires a strong commitment. The benefits include not only restoring the environment, but also improving the sense of community. A watershed is more than just a place—it represents a community with important ideas and values about using and protecting their environment.

WAM Design

The WAM design incorporates the following elements:

- Involvement of the local community.
- A focus on valued watershed and cultural resources.
- Integration of existing environmental programs.
- A comprehensive ecosystem approach.
- Practical and cost-effective assessment tools.
- Credible, interdisciplinary scientific methods.
- Emphasis on long-term commitment to watershed management.

Ecosystem Approach

The WAM process uses an ecosystem approach to better understand watershed conditions and the ecological processes that influence them. An ecosystem approach emphasizes the workings and interactions of the ecosystem resources, such as fish, water quality, and community resources, and processes, such as hydrology, erosion, and vegetation growth. This approach contrasts with traditional environmental assessments that emphasize the understanding of individual components or interactions among a small number of components.

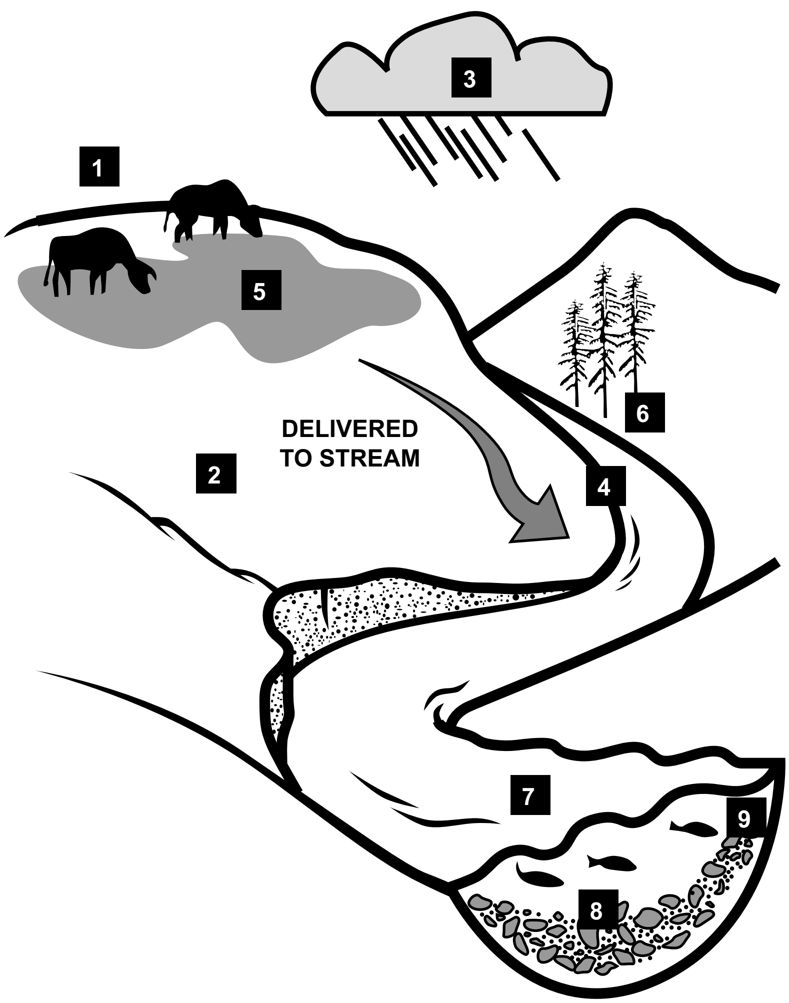
The WAM process considers key ecosystem components and the interactions among physical and biological processes (Figure 2). Important connections among watershed components can be evaluated using the findings of the watershed assessment.

WAM Participation

The watershed group is optimally led by community representatives who have an interest in watershed issues. Environmental professionals are helpful to implement the assessment and carefully evaluate issues in a credible and defensible manner. Long-time residents can provide local knowledge about changes in watershed conditions. Larger and more complicated assessments may also use a facilitator to ensure effective and organized discussion in a neutral atmosphere.

Ultimately, community-wide involvement in the WAM process is important to make long-term changes in watershed management, but each watershed group will need to determine

Figure 2. Key ecosystem components



1 **Cattle Grazing** Cattle grazing is one of many land use activities that can be culturally and economically important to local communities. Grazing can impact natural vegetation, erosion rates, and water quality.

2 **Physical Setting** Soils from various bedrock materials have different erosion potentials and support different types of vegetation.

3 **Climate** Weather patterns and intensity of rainfall are factors driving erosion processes and affecting vegetation patterns.

4 **Topography** Slopes are a significant factor influencing erosion and accessibility for grazing and timber harvest. Slope aspect is also important in determining vegetation patterns.

5 **Vegetation Type** Vegetation communities provide many economic resources (e.g., timber) and cultural resources (e.g., medicinal plants). Reduced vegetative cover or a change in species composition can lead to increased levels of soil erosion.

6 **Riparian Zones** Riparian zones are a critical component of the watershed, providing habitat and ecological functions (e.g., sediment buffer strip, stream shading, and nutrient input to streams).

7 **Water Quality** Water quality conditions dictate the type and status of aquatic life. Sediment from elevated erosion levels can eliminate habitat and introduce other pollutants to the water column. Increased water temperatures can degrade habitat for aquatic species.

8 **Aquatic Life** Fish are often a key ecological, cultural, and economic resource. Aquatic species are also good indicators of watershed ecosystem health. Impacts throughout the watershed are reflected in aquatic habitat conditions.

9 **Stream Channel** The stream channel is a dynamic feature of the watershed with conditions that are defined by a combination of natural physical characteristics. Land-use impacts (e.g., dams, channel dredging or straightening) and natural events (e.g., floods) can significantly degrade channel conditions, reducing or eliminating aquatic habitat. Changes in sediment delivery can modify the composition of the stream bed. Loss of streamside vegetation can increase bank erosion.

the best pathway. For example, the development of watershed partnerships may occur in several stages (Box 5). Creating partnerships to reach consensus and protect valued resources takes time.

Box 5. The Prairie Band of the Potawatomi partnership approach

The Prairie Band of the Potawatomi first identified watershed concerns in Big Soldier Creek using internal staff and consultation with tribal members. Partnerships with the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), Kansas State University, Haskell Indian Nations University, and Royal Valley High School allowed the tribe to characterize watershed conditions and initiate streambank stabilization projects.

Since the watershed area is much larger than the reservation and because of "checkerboard" ownership within the reservation, a broader program of public outreach was initiated. A watershed working group was established with the larger community to create a comprehensive resource management plan. Building these partnerships will allow access to more resources, improve coordination, and develop support and cooperation from tribal members, private citizens, and public agencies.

WAM Time-frames and Resource Needs

The time-frame and resources needed for the WAM process are related to the objectives for conducting the analysis. General planning may require only a few weeks or months. Environmental impact statements or Total Maximum Daily Load (TMDL) plans, however, may require months or years to complete. The actual time and costs of initiating and completing the WAM process will vary depending on the following factors:

- Size of the watershed.
- Availability of staff and resources.
- Amount and accessibility of existing data and information.
- Complexity of the ecological and management conditions in the watershed.
- Amount of work needed to have confidence in the assessment.

Levels of Assessment

Level 1 assessment

Level 1 assessment relies primarily on existing information such as natural resource maps and past environmental reports. Level 1 assessment is a broad-based information gathering effort that can reveal important insights about watershed functions and interactions. Level 1 assessment is qualitative and may result in lower levels of certainty or confidence in the assessment results.

Level 2 assessment

In Level 2 assessment, experienced analysts utilize more data collection, quantitative assessment tools, field surveys, and computer-based models to provide a higher level of certainty or confidence in the assessment results. A Level 2 assessment requires more time and resources than does a Level 1 assessment and may follow a Level 1 assessment when results are indeterminate or vague.

Quality Assurance/Quality Control

The intent of the quality assurance and quality control (QA/QC) procedures embedded in the WAM process is to reduce potential errors in the watershed assessment, ensure the effectiveness of management solutions, and provide repeatability and accountability. Seven elements for meeting QA/QC objectives are included:

1. Joint technical and policy discussion of key watershed issues.
2. Credible scientific assessment methods.
3. Explicit treatment of uncertainty.
4. Identification of key assumptions.
5. Logic tracking to achieve accountability (Box 6).
6. Direct link between watershed assessment and management solutions.
7. Adaptive management feedback through monitoring.

Box 6. Logic tracking

Logic tracking refers to the documentation of the thought process, decisions, and results of each step of WAM. There are a number of tools in WAM to assist in logic tracking:

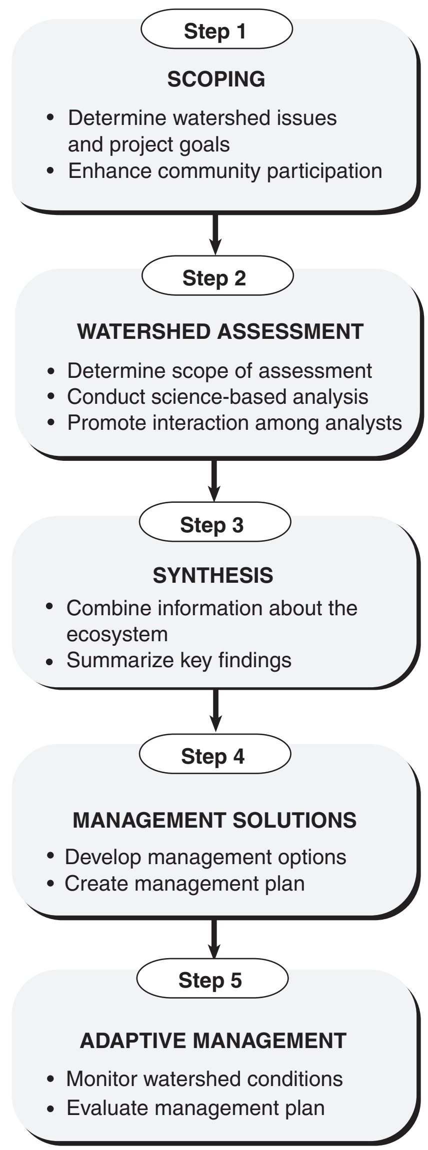
- Lists of critical questions.
- Forms provided in each module to document vital information.
- Map and data requirements in reports.
- Review of key watershed issues.

Logic tracking also provides quantitative and qualitative information that can be used to determine the certainty or confidence level of the assessment results. Assessment methods, data sources, data quality, assumptions of the assessment, and limitations of the results are all documented.

WAM Process

The WAM approach consists of five steps that lead the watershed group through issue definition, assessment, management planning, and monitoring (Figure 3). This guide is intended to be a basic reference for collecting important watershed information. For more detailed analyses, the document lists possible approaches and provides additional technical references. In many situations, it may be infeasible or undesirable to conduct all steps and analyses described in this document. The WAM process should be adapted to integrate existing environmental programs and address priorities unique to each community.

Figure 3. WAM five-step process



Scoping

In the Scoping step, the watershed group will determine the issues to be addressed through the WAM project. The Scoping process also determines how the community will participate in the project. Community-wide participation is desirable as it provides greater input on watershed issues and helps ensure that effective management changes will be implemented.

Watershed Assessment

A set of technical modules provides guidance for assessing the major ecological components of a watershed in a structured and coordinated manner (Box 7). Collectively, the modules are designed to provide a holistic view of the watershed system. The products from these modules are designed to provide compatible information for use in Synthesis.

Box 7. Technical modules

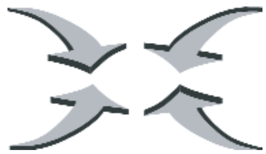
Resource modules identify important resources and determine their sensitivity to changes in environmental conditions:

- Community Resources
- Aquatic Life
- Water Quality
- Historical Conditions

Process modules evaluate the effects of land uses or management practices on the environment:

- Hydrology
- Channel
- Erosion
- Vegetation

Synthesis



The objective of Synthesis is to combine knowledge gained about individual components of the watershed into a comprehensive understanding of watershed issues. Synthesis focuses the assessment on the interactions among land use activities, watershed processes, and resource conditions.

Synthesis is an interdisciplinary exercise and may include both technical analysts and community representatives who participated in Scoping. Synthesis requires participants to look beyond their respective areas of expertise and the analyses conducted in individual modules.

Synthesis results in a number of products designed to take the information generated from the technical modules and create an understanding of the watershed as a system—in other words, to develop the "watershed story." These products document the risks to watershed resources and form the foundation for developing management solutions.

Management Solutions

In the Management Solutions step, the information generated through Watershed Assessment and Synthesis is used to develop specific management options, monitoring needs, and restoration priorities. A management plan is developed with a number of management options to provide flexibility for implementation by the community.

Adaptive Management

The uncertainties in our understanding of natural ecosystems and in the effectiveness of management practices require the use of Adaptive Management. Adaptive Management is the process by which new information about the health of the watershed is incorporated into the management plan. The Adaptive Management section provides guidelines for developing research and monitoring programs to address gaps in information and to measure the effectiveness of management activities.

Examples of WAM Applications

Ideally, the WAM process should be pursued at the initiation of a watershed project. Experience has shown, however, it can be a valuable tool in many related applications. Some of these applications are summarized here; all involved funding or expertise provided by the WAM project. They include an ongoing large-scale, long-term county watershed project in Ohio, a tri-county coalition watershed project in the Snohomish River Basin in Washington State, and development of a watershed field training program. The WAM method has been refined with its application to the development of such watershed plans and training.

Clermont County XLC Project

The U.S. Environmental Protection Agency (EPA) established Project XL, eXcellence and Leadership, to work with interested project sponsors from four categories (facilities, industry sectors, governmental agencies, and communities) to determine whether common sense, cost-effective strategies can replace or modify specific regulatory requirements to produce and demonstrate superior environmental performance. Clermont County, Ohio, is participating in Project XLC (for communities) to develop alternative pollution reduction strategies, focusing on the watershed of the East Fork of the Little Miami River. WAM provided the necessary well-defined, rational process and quality controls for this project.

The project addresses multiple water quality, land use, and economic development issues in the County, while developing a multi-year master work plan for implementation. The work plan includes identifying watershed issues, assessing water quality impacts from existing and future land uses, and developing the appropriate management approaches to prevent water quality impairment while promoting economic development. The XLC Team includes Clermont County, Ohio, The State of Ohio, and XL Co-leads from EPA's Region 5 and EPA Headquarters.

Since XL projects involve replacement or modification of specific regulatory requirements to produce and demonstrate superior environmental performance, they require especially carefully documented processes and quality controls. An expert on the WAM process and quality assurance was given a key role with the team. A Watershed Quality

Management Plan was developed, based on the WAM process, to meet their needs. The following figures are illustrative examples from the Watershed Quality Management Plan. The complex organization of project manager, regulatory agencies, stakeholders, and consultants is shown in Figure 4. The parallel nature of the Project Manager and QA Manager roles is of key importance to ensure objective oversight.

Figure 5 shows the interaction of the Clermont County XLC project participants within the WAM process. The total plan for the multi-year Clermont XLC project is based on the five phases of the WAM process with tasks and products defined under each phase. This has proven valuable in communications as well as in effective project planning and control. Figure 6 shows how the WAM process was used to define the activities and milestones for the lifetime of the Clermont project.

Figure 4. Key partnerships of the XLC project in Clermont County, Ohio

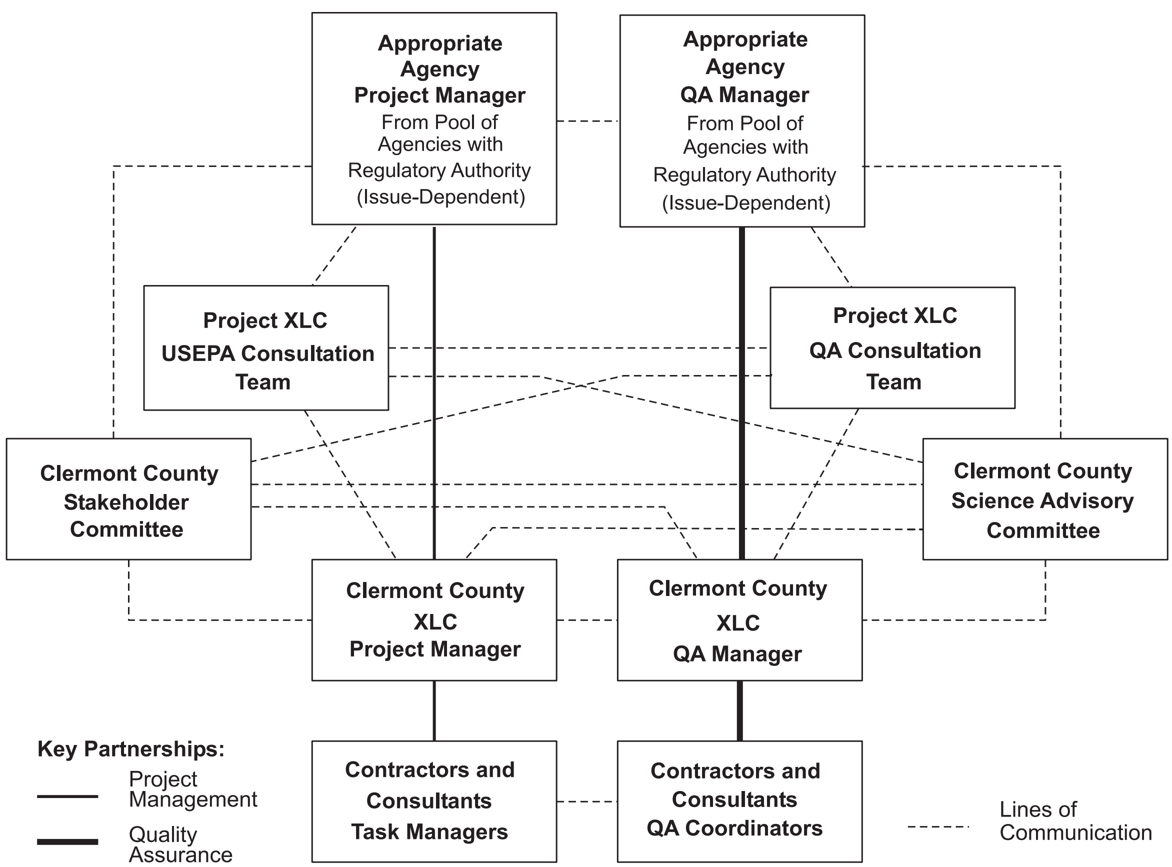


Figure 5. The WAM process for the Clermont County XLC project

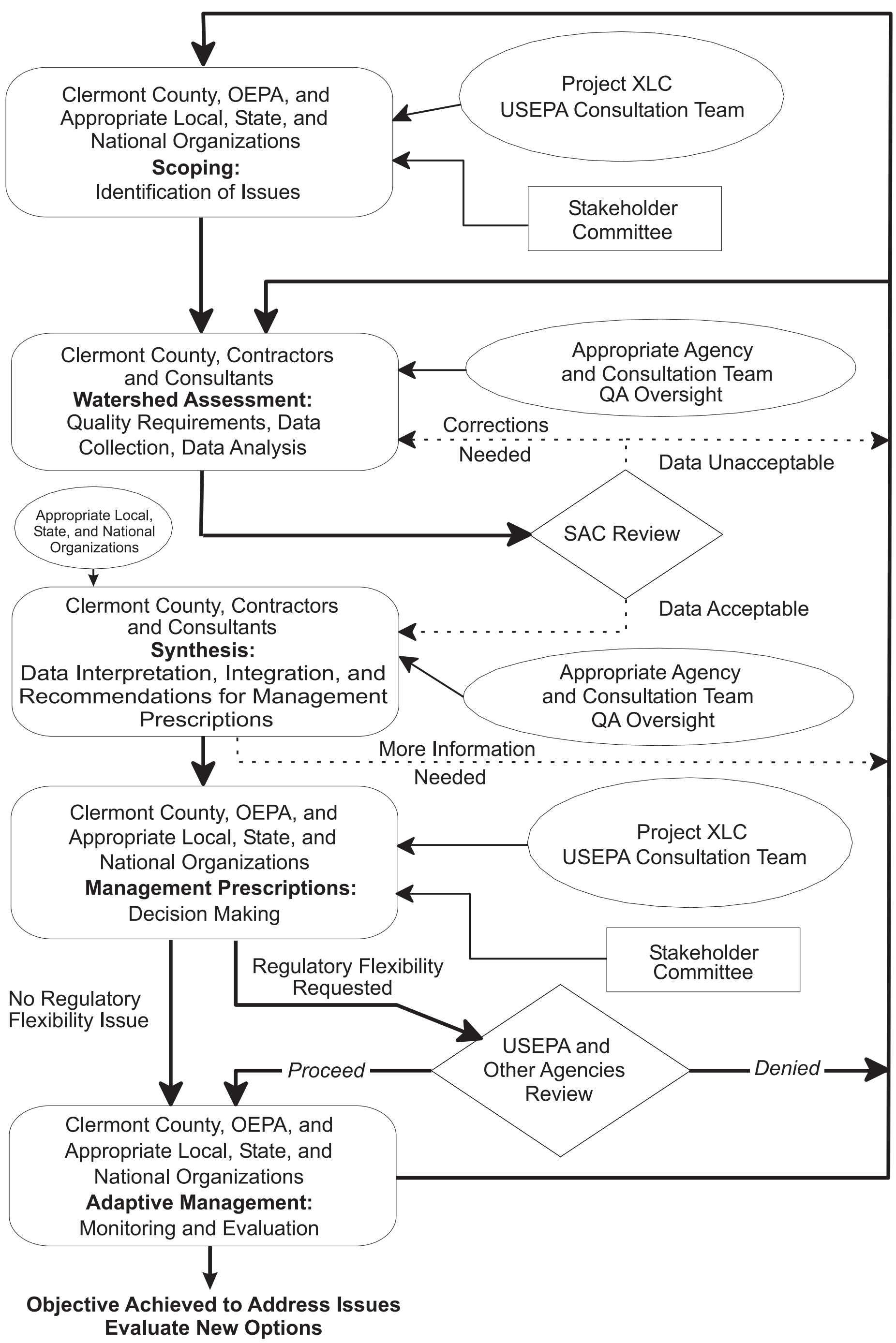


Figure 6. Proposed time line for Clermont County XLC project

Note: "X" = time period in which major effort occurs

"—" = time period in which minor effort occurs

Activities and Milestones	Pre-Project Agreement Activity	2000		2001				2002				2003				2004	
		Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Scoping																	
Identify critical issues	X	X	X	X	X			—	—			—	—			—	—
Establish project objectives	X	X	X			—			—				—				—
Identify and involve stakeholders	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Determine roles and responsibilities	X	X	—	—	—												
Determine data needs, tools																	
Review requirements	X			X	X			X	X			X	X			X	X
Prepare water quality sampling work plan	X				X				X				X				X
Procure contractors/ consultants	X	—	—	—	X	—	—	—	X	—	—	—	X	—	—	—	X
Develop modeling system	X	X	X	X	X	X	X										
Approve Phase I Project Agreement	X	X															
Determine schedule		X	X		—				—				—				—
Prepare Watershed QMP		X	X	X	—	—											
Assessment																	
Acquire data	X	X			X				X	X	X		X	X	X		
Analyze data	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Review data and prepare data summary reports			X				X				X				X		

Figure 6. (continued)

Activities and Milestones	Pre-Project Agreement Activity	2000		2001				2002				2003				2004	
		Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Synthesis																	
Review data summaries and other information				X	X			—	—			—	—			—	—
Evaluate action options for each issue				X	X			—	—			—	—			—	—
Prepare watershed issue summaries					—				X				—				—
Management Prescriptions																	
Develop Watershed Action Plan with recommendations for actions to address the issues					—	—	—	X	X				—	—			—
Stakeholders review and approve									X								
Prepare draft Watershed Management Plan									X	X							
Regulatory flexibility considerations by appropriate agencies										X	X						
Complete Watershed Management Plan					X						X						
Adaptive Management																	
Design monitoring program												X	X				
Monitor actions implemented														X	X		
Evaluate effectiveness of actions															X	X	
Adjust the Plan																X	—

Marshland Watershed Assessment

The Snohomish River basin, located just north of Seattle, Washington, is the second largest watershed draining to Puget Sound (1,856 square miles). The watershed supports significant populations of native fish important to commercial and recreational interests, including coho, chinook, chum, and pink salmon; steelhead, rainbow, cutthroat, and bull trout; and mountain whitefish. The Marshland Watershed Assessment documents historical changes and current environmental conditions. Two species, chinook salmon and bull trout, have been listed as threatened under the Endangered Species Act (ESA).

In response to the ESA listings, the State of Washington is developing a statewide salmon strategy that includes regional and watershed-specific recovery plans. Numerous governmental and non-governmental organizations are represented at the regional level through a tri-county coalition. Policy and technical committees have been formed to develop comprehensive watershed management plans that will lead to the recovery of salmon populations. These plans will address many factors affecting fish populations, including habitat conditions, land use development, artificial hatchery production, and harvest.

The Marshland watershed, within the Snohomish River basin, was chosen to serve as a potential template for other watershed plans within the basin.The WAM framework developed through the EPA is being used to help ensure community participation, an ecosystem approach with defensible technical assessments, and management plans tied directly to the results of the watershed assessment.

The Marshland Watershed Assessment utilized the WAM process to help guide data collection and work with the local community to identify environmental issues and potential solutions. Scoping, the first step in the WAM process, addresses community involvement, problem identification, and project goals. Based on discussions with the Marshland community, Snohomish County, and state and federal agencies, four environmental issues were identified: preserving endangered salmon, protecting homes and agricultural lands from flooding, addressing urban growth impacts, and improving water quality.

Watershed Assessment and Synthesis are the second and third steps, respectively, of the WAM process. The Marshland Watershed Assessment documents historical changes and current environmental conditions (Figure 7) . Major ecological components of the watershed were evaluated using existing information, such as natural resource maps, environmental reports, and monitoring data. The Level 1 assessment relied on information from experts in hydrology, geology, fish biology, ecology, and water quality. Synthesis was used to integrate the assessment results and summarize important findings.

The Marshland community is now conducting the fourth step of the WAM process, evaluating various Management Solutions to their environmental issues. Specific solutions, such as changes in land use practices and restoration of aquatic habitat, are being discussed with the Marshland community and other watershed stakeholders. Further work will be required in this step of the process to evaluate the feasibility of promising or preferred alternatives and to develop a comprehensive watershed management plan. The last step of the WAM process, Adaptive Management, will address the need to monitor conditions and refine the watershed plan as environmental, economic, and social conditions change over time.

Utilization of WAM as a Basis for Watershed Training

The structured approach of the WAM process in well-defined steps and modules also makes it effective as a foundation for watershed training. In order to facilitate use of the watershed approach by tribes with limited experience, the WAM tribal guide was used to develop a watershed field training course. A training guide describes the week-long training course that was designed for a particular watershed on the White Mountain Apache tribal lands in the mountains of eastern Arizona. The training guide, WAM guide, and a training video are now available for use in training.

Figure 8 illustrates the units of instruction, the means of instruction, and the relationship of each unit to the WAM guide. Note that the participants are first introduced to the WAM guide, familiarizing them with the WAM process. The participants are then trained in map interpretation, field investigation, geologic analysis, etc. through a combination of lectures and field trips.

Figure 7. Maps illustrating changes in land use and wetland communities in the Snohomish River basin for the evaluation of watershed restoration options (Collins 2000)

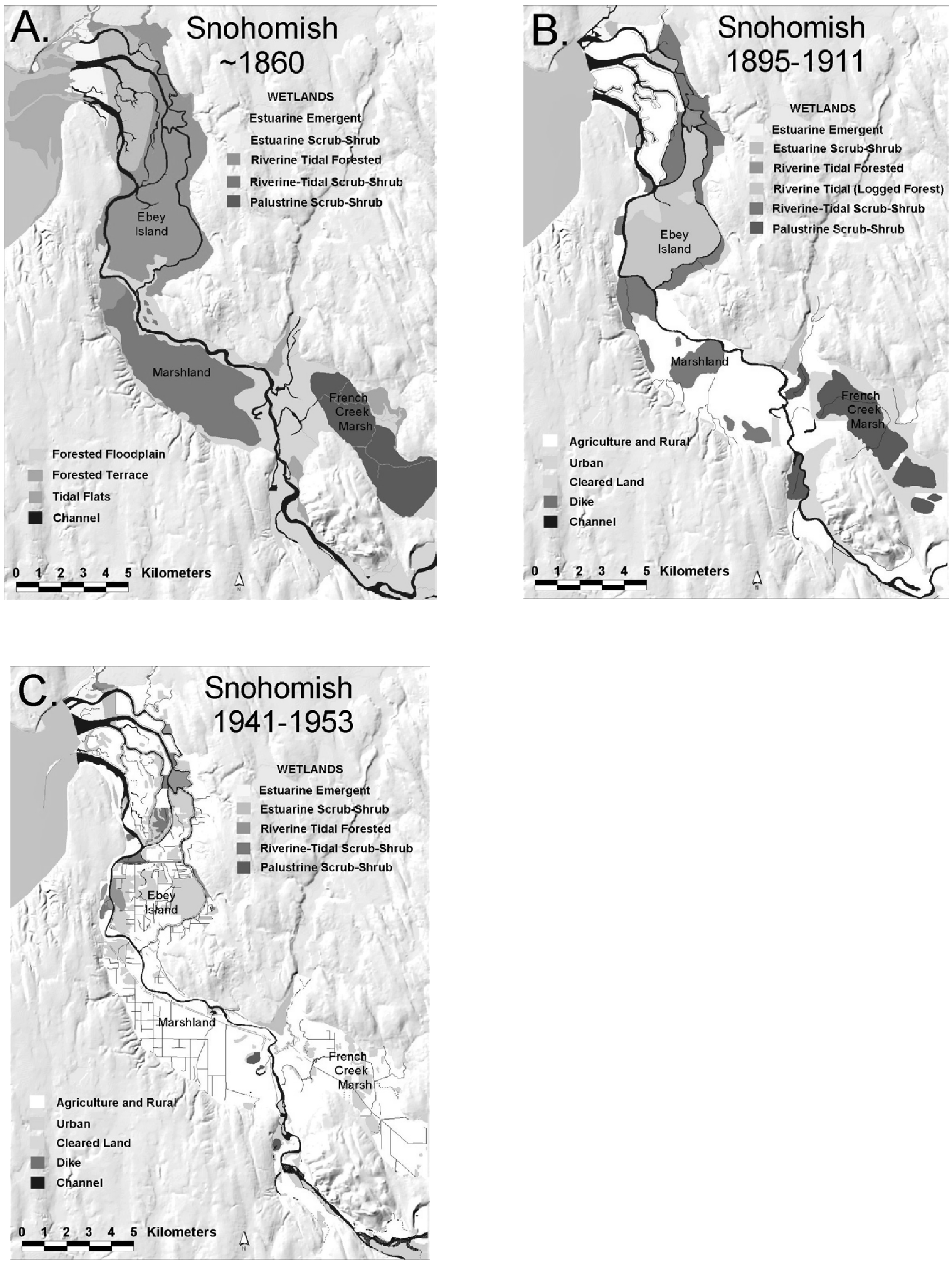


Figure 8. Overview of WAM watershed training program

Unit	Means of Instruction	Relationship to WAM
WAM Introduction	Classroom discussion of introduction materials	Introduction and Overview
Scoping	Discussion of sample watershed issues	Scoping
Assessment	Through units below	Watershed Assessment
Map Interpretation	Lecture, measurements, and map reading activities	Basic skills required for Level 1 analysis; Channel Module
Field Investigations	Four field trips to different project sites	Demonstration of Level 2 analysis techniques; discussion of Adaptive Management at project sites
Aerial Photo Interpretation	Compare changes in land feature through time	Basic skills required for Level 1 analysis; Historical Conditions Module, Erosion Module, Channel Module
Geologic Analysis	Lecture, map interpretation, and sample identification	Erosion Module
Channel	Lecture, field measurements of cross-sections and pebble counts	Channel Module
Soils	Lecture, texture laboratory, game, interpretation of soil survey on field trip	Erosion Module
Ecoregions & Land types	Lecture and map interpretation	Erosion Module; Vegetation Module
Erosion	Lecture, photo interpretation, game	Erosion Module
Hydrology	Lecture, climate activity, game, stream gaging demonstration	Hydrology Module
Water Quality	Field sampling of water quality, water quality analysis with Piper diagram	Water Quality Module
Synthesis (focus on riparian conditions)	Lecture and game	Synthesis; Channel Module, Aquatic Life Module, Community Resources Module
Management Plan Development	Group project and presentation	Synthesis, Watershed Assessment, and Management Solutions

References

Collins, B.D. 2000. Mid-19th century stream channels and wetlands interpreted from archival sources for three north Puget Sound estuaries. Report prepared for the Skagit System Cooperative, Bullitt Foundation, and the Skagit Watershed Council.

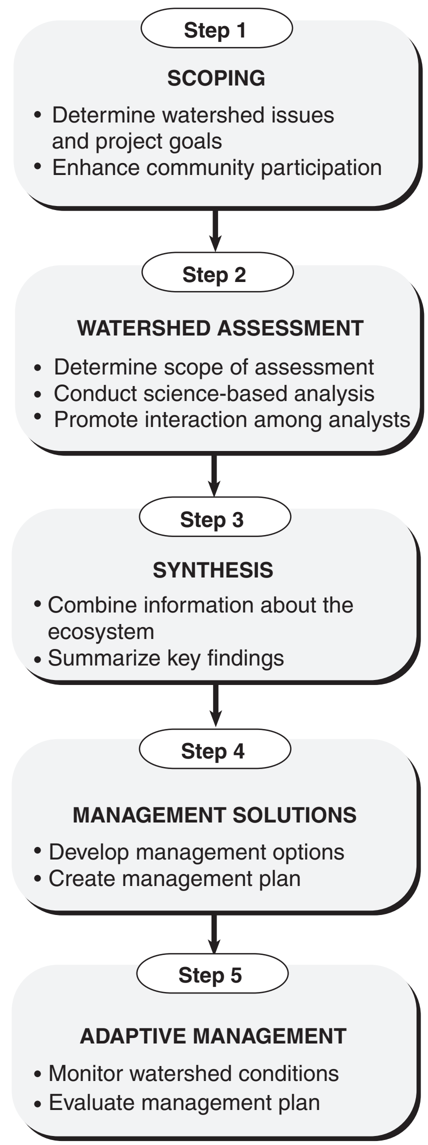
The Watershed Analysis and Management Process

Overview

This portion of the guide describes the methods and tools for implementing the WAM process. The guide is written primarily for environmental professionals who wish to implement a WAM process.

The WAM process comprises five general steps (Figure 1). Detailed guidance on conducting each step is provided in the five corresponding sections of this manual. The following paragraphs provide an overview of how WAM can be used to meet watershed management objectives. The five steps of the WAM process provide a logical progression for conducting an assessment with community involvement, defensible scientific analysis, and credible management, monitoring, and restoration plans to address watershed impacts. The WAM process also allows sufficient flexibility to accommodate varying levels of community participation, technical assessment, and management plan development. Box 1 lists definitions for some commonly used terms in the WAM guide. A glossary at the end of the guide provides definitions for a complete list of technical words and jargon.

Figure 1. WAM five-step process

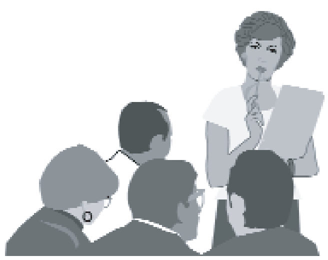


Box 1. Definitions for terms commonly used in the WAM guide

- **Community resource:** an environmental asset that has important cultural and economic value for the people of the region (e.g., drinking water, agricultural land, fish, wildlife).
- **Delivery potential:** the likelihood that a hazardous input will be transported to a community resource.
- **Hazardous input:** any element of the ecosystem that can affect a community resource (e.g., sediment, nutrients, heat).
- **Resource sensitivity:** the responsiveness or susceptibility of the environmental asset to hazardous inputs.
- **Watershed process:** a natural system of interactions in the environment (e.g., water movement, erosion, nutrient cycling).

While this guide advocates a structured and comprehensive approach to watershed assessment, it is important to recognize that watershed-based management is an iterative process that requires an ongoing effort of assessment, planning, monitoring, and communication. Environmental programs that address one or more of these steps may already exist. WAM can help to evaluate and refine these programs to most effectively address watershed-scale problems. Resource management information will need to be collected and analyzed over the long term to provide a sufficient understanding of watershed conditions. It may also take many years of building partnerships to create and implement a watershed management plan for public and private land within the community.

Scoping



The Scoping process helps to organize and focus the leadership of small and large watershed groups on priority watershed issues. The WAM guide provides guidance on developing a goal-oriented strategy, producing realistic action plans, addressing financial needs, and implementing priority projects. It will also help the watershed group decide on how to strategically engage and interact with the local community. Effective changes in watershed management usually cannot happen without broad community involvement and support. The challenges of community participation, however, may necessitate a phased WAM approach that allows for background data collection and more communication time to better address inevitable issues of jurisdiction, overlapping authorities, and risk management.

The Scoping section also discusses important project and information management needs. The WAM process generates a great deal of information that can be valuable when considered in a long-term management framework. It is important to create a process for consistently collecting, storing, and displaying watershed data through tools such as computer databases and geographic information system (GIS) map layers so that results can be summarized and communicated effectively.

Watershed Assessment

The Watershed Assessment step provides an opportunity to collect information about key ecosystem processes that can be used to interpret watershed conditions and help guide restoration efforts. This section provides examples of common watershed issues, the technical modules that typically relate to each issue, and the critical questions within each module that may be applicable. This information can be used to focus the assessment on specific parts of the ecosystem. Consultation among community representatives and the technical team is encouraged to make sure that the appropriate information is collected while maintaining an interdisciplinary and comprehensive assessment. The section also provides guidance on collecting important background information and managing the assessment process.

The Technical Modules are organized into eight sections to evaluate various aspects of the ecosystem. They contain a description of methods and tools that can be customized to address the watershed issues and project goals identified in Scoping. The Community Resources, Aquatic Life, Water Quality, and Historical Conditions modules address the current and historical distribution and condition of important resources in the watershed. The Hydrology, Channel, Erosion, and Vegetation modules address the physical and ecological setting of the watershed and the effects of land use practices over time.

Separating the assessment into technical modules provides a structured approach to ecosystem analysis and the flexibility to focus on critical watershed resources and processes. Critical questions within each technical module provide additional flexibility to refine the analysis and use only the applicable tools and methods. A table at the beginning of each module lists the critical questions along with the kinds of methods or tools available to answer the critical question. Depending on the objectives of the analysis, some modules or critical questions may not be necessary to complete a watershed assessment. Alternatively, modules may be combined into one analysis effort (Box 2).

The methods and tools described in each technical module are divided into two categories: Level 1 and Level 2 assessment. Any combination of Level 1 and 2 assessment

Box 2. Combining modules

Combining tools and methods from multiple modules can provide an efficient and effective assessment process. The following combination of modules may be desirable:

- Community Resources/Historical Conditions
- Erosion/Channel
- Channel/Aquatic Life
- Hydrology/Channel

can be conducted depending on the objectives of the assessment. Level 1 methods and tools rely on existing information to summarize and evaluate the current state of knowledge about the watershed (Box 3). These methods and tools are described in each module as a series of steps to provide useful products and a comprehensive assessment. This "cookbook" approach can be helpful for users who have limited resources or limited experience with watershed-scale assessments. Level 1 assessments generally require a few weeks of work for each module, but the actual time will depend on factors such as the watershed size and availability of data. Box 4 provides examples of the products of a Level 1 assessment.

Box 3. Potential objectives of a Level 1 assessment

- Summarize general watershed characteristics
- Describe key watershed issues
- Identify important gaps in information
- Prioritize further assessment or monitoring needs

Box 4. Summary of possible Level 1 technical module products

Resource Modules

Community Resources
- Locations of community resources
- Map of community resource sensitivities
- Ecological needs of each resource
- Land use impacts on each resource

Aquatic Life
- Map of species distribution
- Assessment of habitat conditions
- Map of habitat sensitivities

Water Quality
- Locations of beneficial uses
- Applicable water quality criteria and standards
- Potential sources of pollutants
- Map of water quality sensitivities

Historical Conditions
- Historical timeline
- Trends in resource conditions
- Map of historical sites

Process Modules

Hydrology
- Climate summary
- Characterization of runoff processes
- Characterization of stream runoff
- Potential land use impacts (e.g., dams, dikes, urban and rural development, irrigation, grazing)

Channel
- Map of stream network
- Channel classification (stream channel gradient and confinement, sinuosity, or other physical features)
- Map of channel types
- Summary of land use impacts

Erosion
- Summary of geology and soils
- Relationship between land use practices and erosion
- Map of erosion hazards

Vegetation
- Map of vegetation communities, riparian areas, and wetlands
- List of threatened and endangered plant species
- Summary of historical changes in vegetation and land use impacts

The Level 2 methods and tools are more technical and typically require experienced analysts (Box 5). The Level 2 section of each module provides a "menu" of approaches that includes for each approach a general description, guidance on its appropriate use, and technical references for more detailed information. The purpose of the Level 2 section is to provide a list of options for a detailed watershed assessment rather than specific directions on how to implement the approach. A Level 2 assessment often requires field surveys and a time frame of several months to complete. The methods also require a good deal of professional judgement to evaluate the applicability of the tools, understand the limitations of the methods, analyze the data, and objectively interpret the results.

Box 5. Potential objectives of a Level 2 assessment

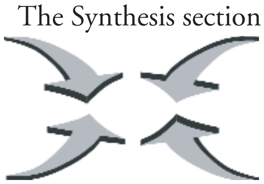
- Supplement existing watershed data to test hypotheses
- Establish cause-and-effect relationships among management activities and watershed conditions
- Delineate specific areas that require special management
- Establish monitoring requirements and criteria
- Identify cost-effective restoration projects

While the modules are separated to provide more flexibility in the assessment, interdisciplinary discussion and shared data collection among technical modules is an important component of the assessment (Box 6). The Synthesis step provides a formal setting for integrating information on various aspects of the ecosystem into a holistic understanding, but integration also occurs during the Watershed Assessment. A great deal of interaction among technical module analysts is necessary to further understanding of complex, interconnected ecosystem processes.

Box 6. Icons

This icon appears in the margins of the technical modules to highlight parts of the assessment for which information exchange and consultation with other module analysts may be helpful.

Synthesis



The Synthesis section describes a process to integrate the results of the Watershed Assessment and to summarize important findings. Synthesis provides an opportunity for formal interaction among different scientific disciplines to provide a more comprehensive picture of the watershed. This part of the WAM process can also provide an opportunity for interaction between technical and non-technical participants to improve understanding of watershed conditions and potential interactions among land uses, watershed processes, and community resources. In addition, Synthesis may be used to help evaluate risks to important resources.

Management Solutions

The Management Solutions section provides guidance on integrating technical information about watershed concerns into an accessible format that can be used to evaluate and develop management options and to create a management plan. Management options may include changes in land use activities, implementation of monitoring plans, or development of restoration plans. The development of management options is generally more effective with community-wide participation, but local, state, or federal agencies may have the ability to implement some management options on their own.

Adaptive Management

The Adaptive Management section describes the role of research and monitoring in addressing gaps in information and ensuring the effectiveness of management solutions (Box 7). The uncertainties in our understanding of natural systems and in the effectiveness of management actions require the use of adaptive management. Guidance is provided to identify specific objectives for new scientific research or development of monitoring plans. This information can be invaluable for developing defensible, long-term watershed management plans.

Box 7. Monitoring objectives

- **Implementation:** Evaluate whether management plan was properly completed
- **Effectiveness:** Examine whether the proposed changes resulted in desired effects
- **Validation:** Confirm assumptions, evaluate predictions, and research trends

Step 1: **Scoping**

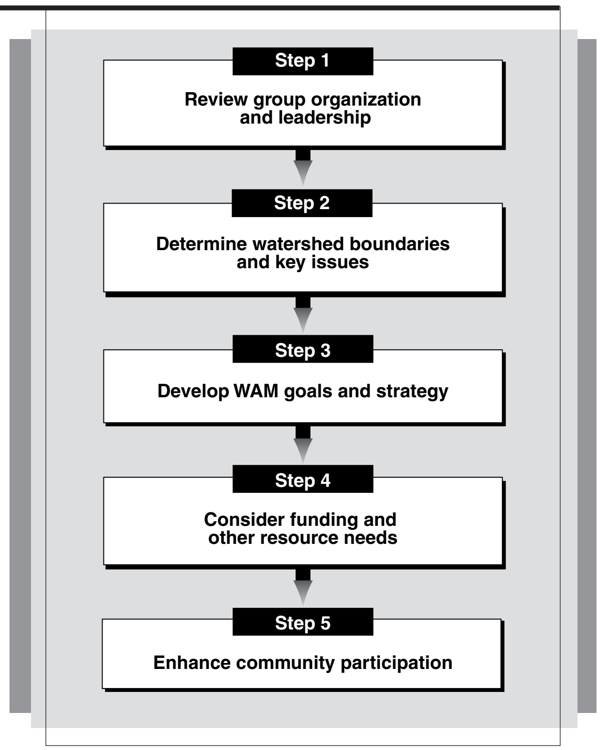
Introduction

Watershed restoration efforts can vary from site-specific projects using local volunteers to regional, multi-governmental partnerships. The Scoping process helps to organize the leadership of small and large communities and focus them on priority watershed issues. The WAM guide provides guidance on developing a goal-oriented strategy, producing realistic action plans, addressing financial needs, and implementing priority projects. It will also help the watershed group decide how to strategically engage and interact with the local community. This engagement will be critical to effectively improve watershed conditions.

Depending on the needs of the watershed group, each step of the Scoping process can be addressed by following the ordered list of actions or specific actions can be considered individually. In either case, Scoping is by nature an iterative process, and the watershed group will want to periodically revisit the issues addressed in this section.

Scoping Process

Step Chart



Procedure

The objectives of the Scoping step are as follows:

- To organize leadership for the WAM process.
- To determine key watershed issues.
- To develop a strategy that addresses priority watershed issues.
- To determine staff and funding needs.
- To determine Watershed Assessment requirements.
- To enhance community participation.

Step 1. Review group organization and leadership

Since each watershed group will have a unique set of people and issues to address, this section cannot provide a specific blueprint for group organization and leadership. Instead, this step identifies important elements to consider in the development and growth of any watershed group (Box 1). The watershed group will need to specifically determine the lines of responsibility and authority for managing various aspects of the watershed program.

Box 1. Choosing WAM project goals

Smaller, less intensive efforts to evaluate watershed conditions can yield important insights about watershed functions and interactions. This type of assessment can help meet a variety of goals:

- Educating the local community about key watershed issues.
- Summarizing current information on watershed conditions.
- Identifying important gaps in knowledge.
- Organizing and prioritizing future actions.
- Conducting pilot projects for monitoring and restoration.

Involving the local community may be particularly important when conducting WAM with limited resources. Staff can often be supplemented with help from local citizens and professionals at county, state, or federal agencies.

Larger, more intensive WAM efforts can provide a more rigorous evaluation to identify cause-and-effect relationships in watershed conditions using science-based assessments. More detailed assessments can help meet goals such as the following:

- Educating and engaging varied interest groups in the watershed.
- Evaluating and supplementing existing watershed information.
- Identifying specific areas that require special management.
- Establishing watershed-specific standards for improved management.
- Planning cost-effective monitoring and restoration projects.

Larger assessments will require more financial and staff resources to manage the process. Soliciting funds from various state and federal grants may be an important part of this process.

- The size of the organization necessary to achieve watershed restoration objectives is typically proportional to the size of the watershed area. A small watershed group working in a large watershed area may want to consider focusing efforts on a smaller area, such as the watershed of a major tributary. Large watersheds generally require a more complex organization to address varied land management issues and resource conditions.

- Most watershed partnerships will involve a number of different interest groups. It will be important to ensure adequate representation for all groups likely to be affected by the watershed management process. However, the social and political dynamics may require a staged approach starting with a small group of like-minded participants and eventually expanding to become more inclusive of all watershed interests. Ultimately, resolution of watershed management issues will depend upon the collaboration of all interested parties.

- A community-driven watershed group will typically have better success engaging key local landowners than will outside agencies or specific interest groups. Whether the watershed group is just starting out or has a long history, establishing and maintaining communication with key landowners or interest groups will be a vital, on-going task to meet watershed restoration objectives.

- The organization and leadership of many watershed groups relies upon government staff and funding, yet important segments of the community may inherently mistrust government involvement. The organization and leadership of the watershed group should be structured to ensure a community-driven prioritization and decision-making process in the context of current rules and regulations.

- Science should play an important role in providing credible information to the watershed management process, but community representatives should ultimately make decisions about watershed priorities and land management changes. The organization and leadership of the watershed group should explicitly address the way in which scientific information will be used in the decision-making process.

- Many larger watershed partnerships are organized with separate policy and technical committees, but completely separating these groups often leads to miscommunication and other problems. Some policy representation at the technical level and technical representation at the policy level can help to maintain good communication and ensure an effective and efficient process.

- Common characteristics of effective watershed groups include being 1) results-oriented, 2) truth-seeking, 3) consent-based, and 4) adaptable (Pajak 2000). Results-oriented means establishing clear, measurable objectives and regularly evaluating results. Truth-seeking focuses on understanding watershed status and trends using credible science. Consent-based groups are generally driven by the local community and involve all stakeholders. Finally, adaptable means the group can work on watershed issues at a small and large scale and use new information to adapt management efforts.

Step 2. Determine watershed boundaries and key issues

The WAM methodology can be applied to any size area and at various scales, depending on the objectives identified. Watersheds are a convenient unit of area for water-related concerns since they typically define the area that can influence surface water. Some areas of the United States, such as the arid Southwest or the limestone-dominated parts of the Southeast, may not have easily defined topographic boundaries, so other assessment boundaries may be necessary. Specific environmental issues often dictate the size and boundaries of the watershed under consideration, but where feasible, focusing on smaller watershed areas on the order of tens of square miles is generally most productive (Box 2).

Box 2. Hydrologic unit codes and watershed boundaries

Hydrologic unit codes (HUCs) developed by the U.S. Geological Survey (USGS) are commonly used by state and federal agencies for defining watersheds at various scales. Most watershed data from agency reports and web sites are organized by HUC. While HUCs may represent scales that are useful for natural resource management, they often do not coincide with the topographic boundaries of the watershed. Where possible, the topographic boundary of the watershed, rather than administrative boundaries, should be used to define the assessment area.

HUCs are based on a four-level classification system that divides the United States into successively smaller hydrologic units. Each hydrologic unit is identified by a unique HUC consisting of two to eight digits based on the four classification levels. The NRCS, together with other state and federal agencies, has further delineated fifth- and sixth-level watersheds in many states. HUCs for these additional watershed levels consist of 11 and 14 digits, respectively, and represent a scale of a few hundred to tens of square miles. Fifth- and sixth-level HUCs are generally a good scale for WAM projects.

Example of HUCs from South Carolina (Bower et al. 1999)

Hydrologic Unit Level	Hydrologic Unit	Hydrologic Unit Name	Hydrologic Unit Area (mi^2)	HUC
1st	Region	South Atlantic Gulf	—	03
2nd	Subregion	Edisto-Santee	23,600	0305
3rd	Accounting Unit (Basin)	Santee	15,300	030501
4th	Cataloging Unit (Sub-basin)	Enoree	731	03050108
5th	Watershed	Unnamed	82	03050108040
6th	Subwatershed	Unnamed	41	03050108040010

Most watershed groups form because of concerns about a specific watershed issue or in response to land management or regulatory changes. The watershed group will need to agree on the issues to be addressed as part of the WAM process (Box 3).

Box 3. Key issues for the Marshland watershed community, Snohomish County, Washington

Flood control and floodplain drainage have traditionally been the largest environmental and economic resource issues in the Marshland watershed. A levee system along the Snohomish River protects farmland and residents from smaller floods, but larger floods have caused significant agricultural and property damage. A network of ditches, a large canal, and a pump plant are used to drain the area and lower the water table to take advantage of the productive floodplain soils. Unfortunately, these projects have blocked access for salmon and drained wetlands that served as important fish and wildlife habitat.

The Marshland watershed has also experienced significant population growth in the last 20 years. The cumulative impacts of increased development on environmental resources, such as water quantity and quality, have not been well addressed. The Marshland Flood Control District faces problems of tributary stream flooding, sediment deposition, and erosion of streams and ditches as a result of both natural processes and recent development in the Marshland uplands. The increased volume of water from residential development also increases the pumping costs for the District to remove water from their fields. Other land management activities, such as forest removal, brush control, draining of wetlands, erosion from fields, and fertilizer and chemical runoff have caused water quality problems and reductions in fish and wildlife populations.

Chinook salmon and bull trout have been listed as threatened species under the Endangered Species Act. Several other wild salmon stocks in the Snohomish River basin are also considered at risk. All of these stocks currently use habitat in the Snohomish River valley and historically used habitat within the Marshland watershed. The Marshland floodplain area could provide critical habitat for the restoration of salmon runs in the Snohomish River basin.

The key issues for the Marshland watershed can be summarized into the following four categories:

1. Fish access and habitat restoration to protect endangered salmon.
2. Maintenance of flood and drainage control to protect homes and agricultural lands.
3. Mitigation of urban development impacts on water runoff and erosion.
4. Improvement of water quality.

The watershed issues identified may be recorded in Form SC1 (Figure 1). Table 1 provides examples of possible watershed issues by land use.

Figure 1. Sample Form SC1. List of watershed issues

Watershed Issue	Affected Resources	Possible Causes
1. Fish can no longer be eaten because of high levels of pollutants	• Bass, salmon, trout • Food and cultural resources important to tribes • Community recreation	• Pulp and paper mill effluent • Stormwater runoff • Naturally high mercury levels
2. Bank erosion and channel entrenchment limit land productivity and degrade water quality	• Loss of farmland • Damage to county road • Loss of cultural sites • Loss of forested floodplain habitat • Reduction in stream habitat	• Larger floods due to urbanization • Inadequate forested buffers along streams • Dikes and dredging • Historical channel straightening

Table 1. Examples of possible watershed issues

Land Use	Aquatic Resources	Water Quality
Agriculture	Fish migrate into drainage ditches where dissolved oxygen levels are too low to support fry emergence.	During spring rains, herbicides run off fields into nearby creek, increasing dissolved nitrogen levels.
Urbanization	New development requires that a formerly unconfined channel be taken underground.	Surface water runoff during spring thaw deposits sediment and road salt into nearby tributary.
Forestry	Increased forest road development and increased culvert placement reduce fish passage for endangered fish.	Deforested watershed contributes sediment to channel.
Mining	Mine tailings with arsenic and other heavy metals contaminate important trout habitat.	Heavy metals concentrations exceed water quality criteria in streams.
Grazing	Dense concentrations of cattle disturb sensitive springs and amphibian habitats.	Nutrient loading from animals have increased algal blooms in slow-moving waters.

Step 3. Develop WAM goals and strategy

Once the watershed group has discussed the key issues, specific goals for the watershed should be identified and refined. Defining watershed goals is one of the most important parts of the WAM process. Both short- and long-term goals for the WAM process may need to be discussed. The watershed group may start by defining broad goals for the organization, which are often described in a "mission statement" or other "statement of purpose." Broad goals can be useful for communication and interaction with diverse interest groups.

More specific goals, however, are usually of greater help for guiding the actions of the watershed group (Box 4). Consider goals that are measurable and attainable over a five- to ten-year period. The group may also benefit from having more project-specific goals that are part of an annual work plan.

Box 4. Examples of broad aquatic resource goals and considerations for refining the goals

- Protect drinking water sources.
  - Consider surface water or groundwater.
- Protect critical aquatic habitat.
  - Define critical areas.
  - Consider options for protection (e.g., acquisition, easement, regulation).
- Restore important aquatic habitat.
  - Identify priority areas.
  - Identify potential types of restoration measures.
- Build public understanding and support in watershed improvement efforts.
  - Target key landowners and businesses.
  - Develop educational programs with schools.
  - Create a website and publish a newsletter.
- Protect waterbodies to meet state water quality standards.
  - Identify potential sources of impairment.

Simply and clearly stating the goals of the group will be an important and effective tool for communication with the community, as well as an important way to measure progress. Also, keep in mind that the determination of watershed goals is an iterative process, and the goals will likely be refined as more information is gathered and stakeholders interact more productively.

Watershed groups often underestimate the amount of time and effort required to accomplish watershed goals. The group should be realistic about current and expected future resources. Small local groups can initiate straightforward improvements through citizen outreach and watershed stewardship programs, whereas larger-scale changes to infrastructure or regulation will require representation by multiple agencies and community leaders (Boxes 5 and 6).

Box 5. Choosing WAM project goals

Smaller, less intensive efforts to evaluate watershed conditions can yield important insights about watershed functions and interactions. This type of assessment can help meet a variety of goals:

- Educating the local community about key watershed issues.
- Summarizing current information on watershed conditions.
- Identifying important gaps in knowledge.
- Organizing and prioritizing future actions.
- Conducting pilot projects for monitoring and restoration.

Involving the local community may be particularly important when conducting a WAM project with limited resources. Staff can often be supplemented with help from local citizens and professionals at county, state, or federal agencies.

Larger, more intensive WAM efforts can provide a more rigorous evaluation to identify cause-and-effect relationships in watershed conditions using science-based assessments. More detailed assessments can help meet goals such as the following:

- Educating and engaging varied interest groups in the watershed.
- Evaluating and supplementing existing watershed information.
- Identifying specific areas that require special management.
- Establishing watershed-specific standards for improved management.
- Planning cost-effective monitoring and restoration projects.

Larger assessments will require more financial and staff resources to manage the process. Soliciting funds from various state and federal grants may be an important part of this process.

Once the watershed goals are defined, the group should develop their strategy or "action plan." The strategy is the process or the steps to be taken to achieve the previously identified goals. The strategy will help define the focus of efforts in more detail and should give guidance on prioritizing projects. A basis in science will help increase the credibility of the strategy, but community values are an equally important consideration in ensuring the long-term commitment necessary for effective watershed improvements.

Box 6. Project goals for the Little Miami River watershed, Clermont County, Ohio

During the development of Clermont County Project XLC, Ohio EPA and a stakeholder committee worked with Clermont County to evaluate ten issues related to the water quality in the East Fork Little Miami River (EFLMR) watershed. An emphasis was placed on considering nontraditional solutions, such as seeking regulatory flexibility from state and federal authorities. The ten issues were as follows:

1. Renew and periodically review NPDES permits in the County's watershed (Milford waste water treatment plant (WWTP), Lower East Fork WWTP, Middle East Fork WWTP, Batavia WWTP, Williamsburg WWTP) based on new water quality findings and determinations.

2. Evaluate the feasibility of point/point trades within the EFLMR to optimize nutrient control between facilities.

3. Consider the development of point/non-point source trading to achieve better controls of nutrients in the watershed, possibly in coordination with Ohio EPA's EFLMR TMDL project.

4. Explore summer low flow augmentation from Lake Harsha to release higher dissolved oxygen waters to improve biological conditions and reduce stress.

5. Review permit options to include seasonal nutrient removal limits.

6. Expedite possible innovative on-site wastewater treatment, disposal and management options for areas of failing or discharging on-site systems.

7. Review the possibility of new discharge to the Little Miami River to accommodate treatment of wastewater from areas with known failing on-site systems.

8. Explore potential for County ownership and management of on-site systems.

9. Evaluate riparian land controls for water quality protection.

10. Non-traditional non-point source control of water quality.

To be placed into the proper context for problem solving, each issue needed further development to identify who needed to be involved in the process (e.g., stakeholders; specific local, state, or national regulatory agencies), what the most appropriate methods for investigating the issue were, and whether the County could perform the work or consultants would be needed.

The strategy is an action plan for the next 10 to 20 years that allows the watershed group to be strategic, rather than opportunistic, in their watershed recovery efforts. The rationale for choosing certain priorities or actions should be clearly stated within the strategy. The following elements may be helpful in crafting a site-specific watershed strategy:

- **Geographic Priorities:** Are certain sub-basins or stream reaches of particular importance (e.g., unique, productive, critical habitat component) based on best available knowledge?

- **Community Priorities:** Are recovery efforts in certain areas important to engage community support for the entire watershed?

- **Assessment:** What information gaps will need to be filled in order to prioritize or implement recovery efforts?

- **Protection:** Are there priority areas where current practices are ineffective in protecting watershed resources?

- **Restoration:** Is the focus on protecting intact, high quality habitat or restoring historically productive habitat?

- **Monitoring:** How will the group measure progress in achieving the watershed objectives?

- **Community:** How will key landowners and community leaders be engaged to participate in priority watershed protection and recovery efforts?

The strategy should be summarized in no more than a few pages so that the community can easily understand the rationale and outcomes of implementing the strategy (Box 7).

Step 4. Consider funding and other resource needs

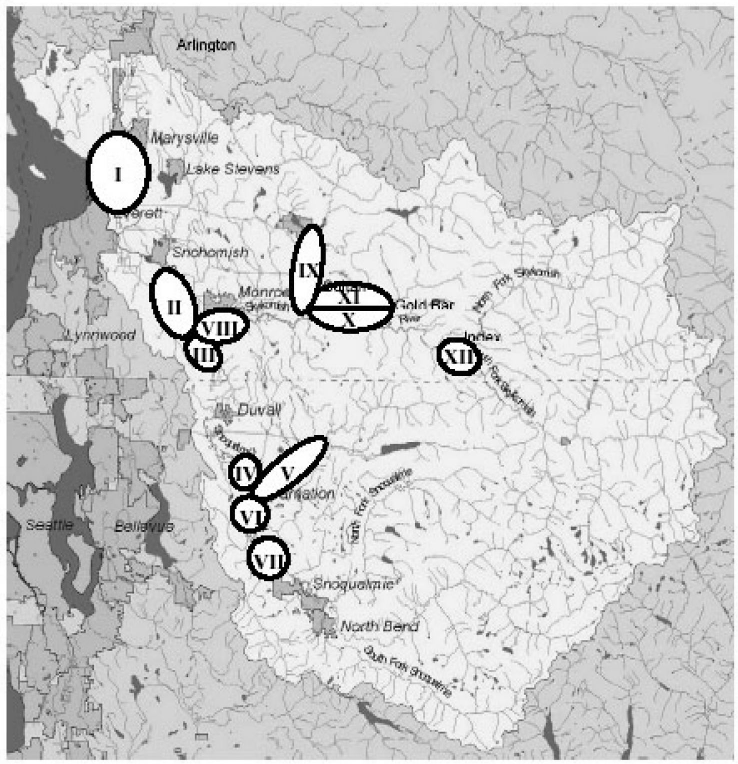
The financial resources available to a watershed group can vary significantly. However, even groups with minimal resources can conduct important elements of the WAM process and significantly improve watershed conditions. Many of the tools and methods described in the WAM process rely on local expertise and relatively inexpensive materials. Professionals from local government agencies, colleges, and universities are often available to help collect and interpret information. Community outreach will be a key component for watershed groups to recruit volunteers and other contributions.

Box 7. Developing a protection and restoration strategy for the Snohomish River basin, Washington

Focus Area Concept

In the Snohomish River basin, "focus areas" support high levels of spawning, rearing, holding, or refuge for chinook salmon. Focus areas are determined from biological data on the level of habitat use. In addition to areas with high current use, other important areas include sites of high historical but low current use and sites with high but inconsistent use (map).

Near-term focus areas for restoration and protection projects



Selection of Focus Areas

Local experts, including state and tribal biologists, compiled salmon distribution data to identify areas that support high densities of chinook salmon. These focus areas will become the building blocks for salmon conservation in the watershed. Future efforts will 1) link the focus areas to other current and historical fish habitat, 2) link areas that maintain the watershed processes important to supporting high quality salmon habitat, and 3) extend this strategy to address the habitat needs of bull trout, coho, and other salmon species.

Habitat Condition Analysis

Habitat conditions were analyzed to help choose the appropriate type of protection and restoration projects. Local experts performed the analysis with a panel of five scientists reviewing their work and conclusions.

Project Identification

Watershed stakeholders identified specific projects in the focus areas based on the characterization of current habitat conditions. Participants used aerial photographs and detailed maps showing natural features, such as wetlands, and land use information, such as dike locations and zoning boundaries. The participants also considered linkages between past and future projects, time-sensitive opportunities and risks, and whether key watershed processes were intact.

Strategic Project List

A basin-wide workshop was held to review suggested projects for each focus area and to develop a strategic list of project ideas. Land acquisition or conservation easements along riparian corridors are a key part of the habitat strategy, as are more complex restoration projects, such as the removal or modification of flood control levees. Many of these projects will require detailed feasibility studies to address issues such as public safety and the protection of homes, businesses, farmland, and infrastructure. Restoration projects will require working with key landowners and building community support.

(Adapted from *Snohomish Basin Salmon Recovery Forum 2001*)

Box 8. Federal granting agencies

The following federal agencies manage grant programs that may help to support watershed-related work:

- U.S. Army Corps of Engineers
  - Section 206 Program
  - Section 22 Program
- U.S. Department of Agriculture, Natural Resources Conservation Service
  - Wetland Reserve Program
- U.S. Environmental Protection Agency
- U.S. Geological Survey
- U.S. Fish and Wildlife Service
- National Marine Fisheries Service
  - Community-Based Restoration Program

Some watershed groups may reach a stage at which increased funding will be necessary to accomplish their goals. Financial grants are commonly available from various private and public institutions, including local, state, and federal government agencies (Box 8). The group should understand that the process for acquiring and managing a financial grant might take a large amount of effort and supplemental resources. Project development, project management, and administrative requirements can be significant for many grant programs. Local government agencies and non-profit organizations may have staff with experience in grant writing and administration.

The time frame and resource needs for conducting the WAM process will depend on the watershed issues, the project goals, and the scale of the assessment. The actual time and costs associated with the WAM process will vary depending on the following factors:

- Size of the watershed.
- Availability of staff and resources.
- Amount and accessibility of existing data and information.
- Complexity of the ecological and management conditions in the watershed.
- Amount of work needed to achieve acceptable levels of confidence.

WAM outlines a framework for evaluating environmental problems and developing effective management solutions that should increase opportunities for funding. Involving the local community, understanding ecological processes, and using defensible, science-based assessment are important elements for many state and federal grants. Groups can also take advantage of in-kind support from public agencies or citizen groups through cooperative projects, cost-share programs, or technical assistance, rather than seeking additional grants.

The *Catalog of Federal Funding Sources for Watershed Protection* (U.S. Environmental Protection Agency [EPA] 1999) lists a variety of federal monetary grants with contacts and internet sites to obtain further information. It also provides a list of publications and private, non-profit organizations that may provide additional sources of funding.

Step 5. Enhance community participation

The most effective watershed groups across the country actively engage and involve the local community. Building support in the community to better address watershed issues is vital to implement effective, long-term solutions. Cooperators such as local, state, and federal agencies may be able to provide staff and other valuable resources to strengthen the watershed recovery efforts. If the results of the WAM process are to influence regulatory decisions, support applications for public funding, or have credibility in the affected communities, full community participation is desirable.

The following potential participants may be vital to the WAM process (EPA 1997):

- Private companies and landowners whose livelihoods depend on watershed resources.
  - Farmers and ranchers.
  - Fishermen.
  - Timber companies.
  - Developers.
  - Fishing and hunting guides.
  - Utility companies.

- Offices of local, state, tribal, and federal governments.
  - Local watershed organizations and conservation districts.
  - State and county departments of environmental protection.
  - NRCS.
  - USDA Forest Service (USFS).
  - EPA.

- Organizations that use the watershed or that are concerned with watershed or land use issues.
  - Water recreation organizations.
  - Public health organizations.
  - Community economic development organizations.
  - Environmental groups.

Conducting Community Meetings to Enhance WAM Participation

Depending on the size of the watershed and the population distribution, one or more Scoping meetings can help inform and engage the local community (Box 9). The objectives of the Scoping meeting are to 1) provide an open forum for public input, 2) prioritize watershed issues, and 3) provide ideas on watershed goals. The focus of the meeting should be to share information and generate ideas in a neutral and cooperative atmosphere.

Box 9. Citizen involvement, Flagstaff, Arizona

The City of Flagstaff needed to update its growth management guide. The city brought together the USFS, the State Land Department (which managed properties within the city boundaries), and the National Park Service (which was slated to expand its boundaries). The initial issue on the table was the interface of open space and urban areas. Through discussion, however, other issues arose, such as the migration of elk and other large animals across highways and through residential areas, development pressures, and floodplain protection.

Although local, state, and federal agencies did much of the preliminary work, the group quickly opened the process to community participation. Participation was encouraged from city and county representatives, the Native American population, the Sierra Club, Northern Arizona University, and the citizens of Flagstaff. As the group grew and opinions were shared, the actual goals of the group evolved, incorporating a more complete set of concerns from the community.

Adapted from EPA (1997)

Collect background material

Maps, individually or in atlases, and other basic watershed information are readily available from map stores, university libraries, natural resource agencies, and the Internet. The EPA's "Surf Your Watershed" website (***http://www.epa.gov/surf***) is a good place to start collecting maps and other watershed information. The NRCS (***http://www.nrcs.usda.gov/TechRes.html***) and the USGS ***(http://mapping.usgs.gov)*** are also good sources for maps and other landscape information (Box 10).

Depending on the size of the watershed and complexity of watershed issues, it may be helpful to choose one person whose main responsibility is to manage the storage and flow of information.

Box 10. Create an information management system

Documenting the decision-making processes, storing map data, cataloging information, and sharing information are key components of WAM QA/QC. The following tools can be used to facilitate information management:

- GIS to store map data and generate maps.
- Computer databases to store information.
- Electronic mail list serve or web site to facilitate communication.

The following materials are helpful for most Scoping meetings and should be prepared prior to the meeting:

- **Base map.** A topographic or GIS map with watershed boundaries, administrative locations (township boundaries, towns, highways, or other sites to help orient people), and larger waterbodies (streams, lakes, wetland complexes).
- **Land use map.** A large-scale map that generally identifies the locations of various land uses in the watershed. Land zoning maps may be a useful source for this information.
- **Land ownership map.** A map that shows the general ownership pattern. A simple map that differentiates between public and private lands may be sufficient.
- **Ecoregion map.** A map that shows areas with relatively uniform ecological systems (Box 11).
- **Environmental maps.** Other readily available maps of vegetation communities, wetlands, geology, soils, or precipitation may be useful.
- **Watershed resources map.** A map that generally shows the location of important community resources, such as swimming areas, drinking water sources, and critical fish and wildlife habitat. This map can be refined during the Scoping meeting to capture all important community resources.
- **Environmental reports.** General reports on past and present environmental characteristics such as water quality, aquatic habitat, water use, flooding history, climate patterns, erosion, wetlands, or vegetation are often available from environmental impact statements, hydroelectric dam licensing reports, and other watershed assessments.

Box 11. Ecoregions

Ecoregions are defined as areas with a relatively uniform pattern of terrestrial and aquatic ecological systems. Delineation of ecoregions can help resource managers better understand regional relationships of climate, topography, geology, soils, and vegetation that influence aquatic habitats. Ecoregions can be an effective aid for inventorying and assessing environmental resources, setting resource management goals, and developing biological criteria and water quality standards. Omernik and Bailey (1997) provide a good discussion of the differences between ecoregions, watersheds, and hydrologic units.

Two similar approaches to ecoregion mapping from the EPA (Omernik 1995) and the USFS (Bailey 1987, 1995a, 1995b) are readily available. For a description of the EPA's approach to ecoregion mapping consult the website at ***http://www.epa.gov/bioindicators/html/usecoregions.html***. Level III and IV mapping will be most useful for WAM. For information on the USFS approach to ecoregion mapping, consult the publication "Ecological Subregions of the United States" (***http://www.fs.fed.us/land/pubs/ecoregions/ecoregions.html***). Ecoregion mapping at the section or subsection scale will be most useful for WAM. This report also has an extensive bibliography with maps and other information on landscape characteristics organized by region.

- **Photographs.** Standard and aerial photographs are often useful for illustrating various watershed conditions or issues.

Organize meeting logistics
Depending on the scale and amount of community participation for the Scoping meeting, the following preparations may need to be made:

- **Select a convenient time and location.** An evening meeting may be necessary to get full community participation. A neutral meeting place such as a school or community center may be preferable to government agency offices.

- **Develop an agenda.** A list of discussion topics and a schedule should be provided prior to the meeting. Try to solicit speakers from various agencies and interest groups to share information and discuss projects being conducted in the watershed.

- **Prepare meeting notices and invitations.** The Scoping meeting can be advertised in local newspapers, newsletters, or other public forums. Invitations to community groups or individuals may also be sent out along with an information packet. The information packet could include one or more of the following items:

    - A general watershed map.
    - A summary of watershed issues.
    - A synopsis of the WAM process.
    - A meeting agenda.
    - A questionnaire about community concerns.

- **Promote focused discussion.** It will be important to clearly define objectives for the meeting and encourage sharing of ideas and opinions by asking questions and checking for consensus. Consider which issues may have the greatest potential for conflict between stakeholders. For example, conflicts often arise between rural and urban communities, which may have different land use interests. A facilitator may be helpful for mediating discussions and staying on schedule.

- **Record ideas and minutes for meeting.** Two people will often be needed to help record ideas on a flip chart and to summarize the minutes of the meeting. For less formal meetings, volunteers from among the Scoping participants may be used to help record this information.

The following sources provide more information on conducting such meetings:

- *Leadership Skills: Developing Volunteers for Organizational Success* (Morrison 1994).
- *Solving Community Problems by Consensus* (Carpenter 1990).
- The "Know Your Watershed" website (***http://www.ctic.purdue.edu/KYW***).

Conduct meeting and prioritize key watershed issues

One crucial output from the Scoping process is the discussion of key watershed issues and how human activities may be impacting community resources. The watershed issues should outline the perceived connections between human land uses, the response in watershed conditions, and community resource impacts.

Visually displaying the location of community resources and areas of concern can be a useful organizational and learning tool for meeting participants. To promote interaction and discussion, participants can be asked to draw locations of community resources directly onto a land use map. Alternatively, the land use and watershed resource locations can be combined on one map or placed on clear mylar to allow for map overlays. Any other readily available information on the watershed can also be used in a map overlay fashion to illustrate connections between landscape and resource conditions.

If the watershed group has already identified their key watershed issues, the issues should be shared with the larger watershed community. Community participants may identify new issues or emphasize different aspects of issues that will require changing or broadening the WAM goals. Be sure to create goals consistent with the commitment of stakeholders and the availability of funding and other resources. Once the WAM goals are finalized, record them on Form SC2.

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Form SC1. List of watershed issues

Watershed Issue	Affected Resources	Possible Causes

Form SC2. WAM project goals

Project Goal	Assessment Level

Step 2: Watershed Assessment

Introduction

The Watershed Assessment step provides an opportunity to collect information about key ecosystem processes that can be used to interpret watershed conditions and help guide restoration efforts. The Watershed Assessment can be used for some of the following purposes:

- To document current and historical watershed conditions.
- To identify important gaps in knowledge.
- To analyze the limiting factors most affecting aquatic species.
- To conduct pilot projects for monitoring and restoration.
- To establish watershed-specific standards for TMDLs.

The Watershed Assessment relies on an interdisciplinary, science-based approach to gather information about ecosystem processes, resource conditions, and historical changes. Changes in resource conditions can be due to specific practices and events or can be a result of the cumulative effects of management practices throughout the watershed. Various aspects of the ecosystem are evaluated using a series of technical modules that provide guidance on analyzing watershed conditions (Box 1). Each technical module contains a description of methods and tools that can be customized to address the watershed issues and project goals identified in Scoping.

Box 1. Technical modules

Resource modules identify important resources and determine resource sensitivities to changes in environmental conditions:

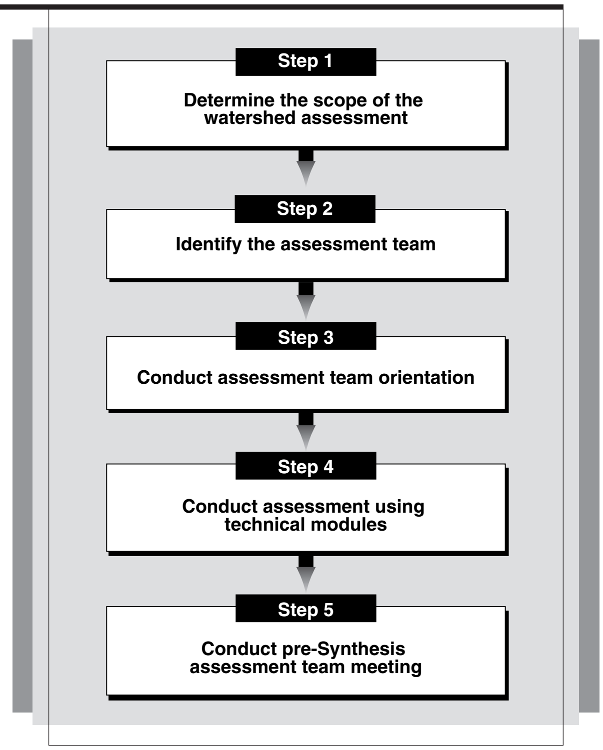
- Community Resources
- Aquatic Life
- Water Quality
- Historical Conditions

Process modules identify impacts caused by land uses or management practices:

- Hydrology
- Channel
- Erosion
- Vegetation

Watershed Assessment Process

Step Chart



Procedure

The objectives of the Watershed Assessment step are as follows:

- To define the type of technical analyses necessary to meet WAM project goals.
- To conduct defensible, science-based assessment at a watershed scale.
- To promote interaction among scientific disciplines.
- To identify connections among ecosystem processes, resource conditions, and human activities.
- To effectively summarize watershed conditions, land management influences, and information gaps.

Step 1. Determine the scope of the watershed assessment

Representatives from the watershed group who participated in the Scoping process should review the key watershed issues and project goals with technical staff who will be working on the Watershed Assessment. This discussion will help to ensure that the Watershed Assessment will meet the proposed project goals (Box 2). The technical staff should discuss the following questions with the watershed group representatives:

- Which technical modules are needed to address the key watershed issues?
- Which critical questions need to be addressed by the Watershed Assessment?
- Where are Level 1 methods sufficient to meet project goals?

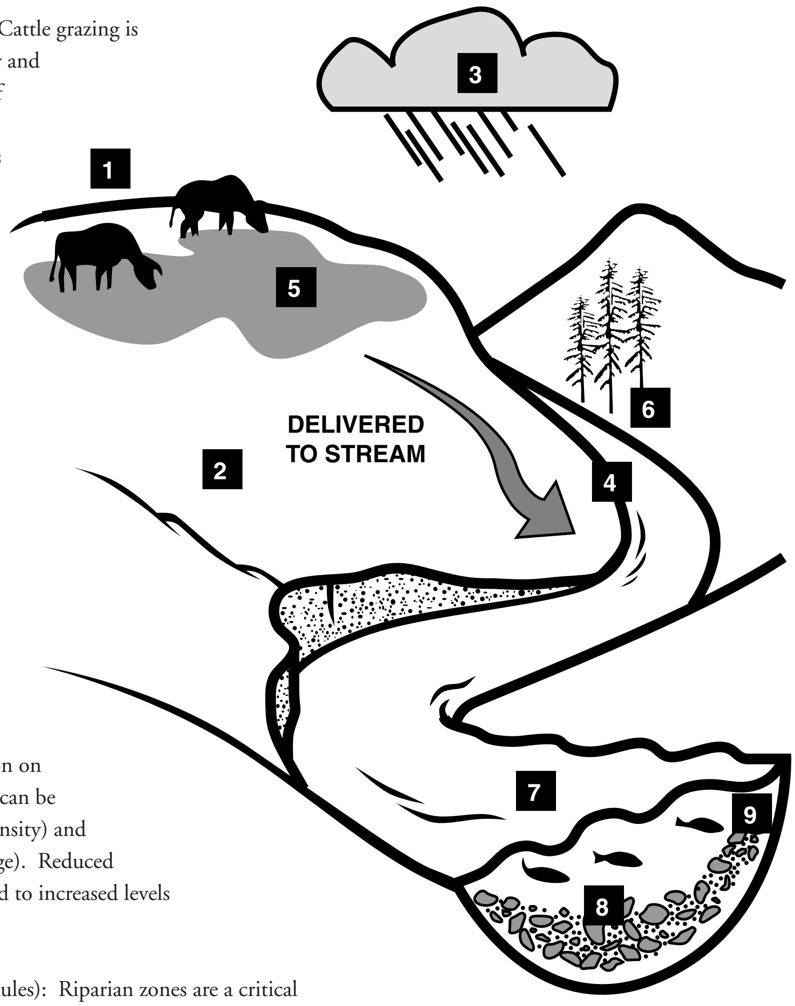
- Where are Level 2 methods necessary to meet project goals?
- How can existing studies or monitoring programs be integrated into the assessment?
- Are there sufficient resources available to conduct the assessment?
- What is a realistic schedule to complete the Watershed Assessment?
- What issues will require long-term data collection?

Box 2. Determining the appropriate scale for the Watershed Assessment

Defining the appropriate scale at which to assess watershed conditions can be a difficult issue. Land management practices may ultimately require site-specific evaluations, but conducting a technical assessment at this scale (typically a map or photo scale of 1:5,000 or smaller) is typically not feasible or desirable for an entire watershed given time and cost constraints. A larger scale, such as 1:50,000 or 1:100,000, may be more economical for addressing larger watershed issues such as regional planning but may lack the resolution necessary to recommend effective management and protection strategies within the watershed. Working at a scale of between 1:15,000 and 1:30,000 often provides cost-effective coverage and meaningful results that can be translated to site-specific projects. It should be emphasized, though, that even at this scale further work will inevitably be required to address problems at the site level. Whatever scale is used, map products should use a consistent scale to aid comparisons and allow for map overlays.

A useful tool for outlining the watershed issues and assessment needs is the creation of conceptual models. Figure 1 is a conceptual model illustrating components of the ecosystem that would need to be considered to evaluate impacts of cattle grazing. Each component of the model has an associated technical module to illustrate the potential scope of the assessment. Within the technical modules, critical questions are provided that can be used to further refine the scope of the assessment. Table 1 lists some common watershed issues and the modules and associated critical questions that address each issue.

Figure 1. Conceptual model for evaluating grazing impacts



1 **Cattle Grazing** (Community Resources module): Cattle grazing is one of many land use activities that can be culturally and economically important to local communities. The goal of watershed assessment is to ensure that these activities are conducted in a manner that can be sustained and that does not negatively impact the ecosystem.

2 **Physical Setting** (Erosion module): Identification of soils and parent material is essential to understanding erosion processes. Soils from various bedrock materials have different erosion potentials and support different types of vegetation.

3 **Climate** (Hydrology module): Consideration must be given to weather patterns and intensity of rainfall as factors driving erosion processes and affecting vegetation patterns.

4 **Topography** (Hydrology module): Slopes are a significant factor influencing erosion and accessibility for grazing. Slope aspect is also important in determining vegetation patterns.

5 **Vegetation Type** (Vegetation module): Information on current and historical conditions of vegetative cover can be critical to understanding system capacity (e.g., grazing intensity) and changes over time due to historical uses (e.g., reduced forage). Reduced vegetative cover or a change in species composition can lead to increased levels of soil erosion.

6 **Riparian Zones** (Vegetation and Aquatic Life modules): Riparian zones are a critical component of the watershed, providing habitat and ecological functions (e.g., sediment buffer strip, stream shading, and nutrient input to streams).

7 **Water Quality** (Water Quality module): Water quality conditions dictate the type and status of aquatic life. Sediment from elevated erosion levels can eliminate habitat, warm water to critical levels, and introduce other pollutants to the water column.

8 **Aquatic Life** (Aquatic Life module): Fish are often a key ecological, cultural, and economic resource. Aquatic species are also good indicators of watershed ecosystem health. Impacts throughout the watershed are reflected in aquatic habitat conditions.

9 **Stream Channel** (Channel module): The stream channel is a dynamic feature of the watershed with conditions that are defined by a combination of natural physical characteristics. Changes is sediment delivery can modify the composition of the stream bed, and loss of streamside vegetation can increase bank erosion.

Table 1. Examples of watershed issues and applicable modules and critical questions

Watershed Issues	Modules	Critical Questions*
Floods	Hydrology	**H1:** What is the seasonal variability in streamflow? **H7:** What are the potential land use impacts to hydrologic processes in the watershed?
	Channel	**C2:** How do climate and the frequency, magnitude, duration, and timing of floods affect channel conditions?
	Historical Conditions	**HC2:** What are the natural setting and disturbance regimes in the watershed?
Drinking water	Water Quality	**WQ2:** What water quality parameters do not meet the standard and for what time period?
	Hydrology	**H6:** For which beneficial uses is water primarily used in the watershed, and are surface water or groundwater withdrawals prominent?
	Community Resources	**CR4:** What processes or land use activities may be impacting community resources?
Floodplain/riparian conditions	Vegetation	**V4:** Does existing upland, riparian, or wetland vegetation differ substantially from historical conditions? **V6:** What are the important functions of riparian vegetation relative to watershed processes?
	Community Resources	**CR2:** Where are community resources located?
	Aquatic Life	**AL3:** What are the requirements of various life history stages of the aquatic species?
	Hydrology	**H5:** What water control structures are present in the watershed?
	Channel	**C5:** How and where have changes in riparian vegetation influenced channel conditions?
Algae blooms/ eutrophication	Water Quality	**WQ7:** What causes excessive algae growth or eutrophication?
	Aquatic Life	**AL5:** What connections can be made between past and present human activities and current habitat conditions?
Water temperature	Water Quality	**WQ2:** What water quality parameters do not meet the standard and for what time period?
	Aquatic Life	**AL3:** What are the requirements of various life history stages of the aquatic species?
	Vegetation	**V6:** What are the important functions of riparian vegetation relative to watershed processes?
Loss of rare native plant	Community Resources	**CR2:** Where are community resources located? **CR4:** What processes or land use activities may be impacting community resources?
	Vegetation	**V1:** What are the primary vegetation categories that exist in upland areas? **V4:** Does existing upland, riparian, or wetland vegetation differ substantially from historical conditions?

* **H1** = Module and critical question number

Modules: **AL** = Aquatic Life, **C** = Channel, **CR** = Community Resources, **E** = Erosion, **H** = Hydrology, **HC** = Historical Conditions, **V** = Vegetation, **WQ** = Water Quality

Table 1. (continued)

Watershed Issues	Modules	Critical Questions*
Wetlands functions and values	Hydrology	**H3:** What are the roles of groundwater and natural storage features in the watershed?
	Vegetation	**V3:** What are the primary vegetation categories that exist in wetland areas?
		V7: What are important functions of wetland vegetation relative to watershed processes?
	Aquatic Life	**A3:** What are the requirements of various life history stages of the aquatic species?
	Community Resources	**CR2:** Where are community resources located?
Bank erosion	Erosion	**E10:** How significant a sediment source is streambank erosion, and how have erosion rates changed over time?
	Hydrology	**H1:** What is the seasonal variability in streamflow?
	Vegetation	**V6:** What are the important functions of riparian vegetation relative to watershed processes?
	Channel	**C1:** How does the physical setting of the watershed influence channel morphology?
		C3: How and where has the behavior of the channel changed over time?
	Water Quality	**WQ9:** What conditions lead to excessive turbidity?
Fish consumption advisories	Aquatic Life	**A2:** What are the distribution, relative abundance, population status, and population trends of the aquatic species?
	Water Quality	**WQ5:** What causes fish consumption advisories?
Dams	Hydrology	**H5:** What water control structures are present in the watershed?
	Channel	**C10:** How does the presence and management of dams and levees affect channel conditions?
	Aquatic Life	**A5:** What connections can be made between past and present human activities and current habitat conditions?
	Historical Conditions	**HC3:** Where and when have landscape changes occurred in the watershed?
Threatened or endangered aquatic species	Aquatic Life	**A5:** What connections can be made between past and present human activities and current habitat conditions?
		A2: What are the distribution, relative abundance, population status, and population trends of the aquatic species?
	Channel	**C11:** What is the potential for change in channel conditions based on geomorphic characteristics?
	Erosion	**E12:** What are the primary sources of sediment delivery to waterbodies?
	Vegetation	**V6:** What are the important functions of riparian vegetation relative to watershed processes?
	Hydrology	**H6:** For which beneficial uses is water primarily used in the watershed, and are surface water or groundwater withdrawals prominent?

* **H1** = Module and critical question number

Modules: **A** = Aquatic Life, **C** = Channel, **CR** = Community Resources, **E** = Erosion, **H** = Hydrology, **HC** = Historical Conditions, **V** = Vegetation, **WQ** = Water Quality

Technical advisors may want to discuss hypotheses about watershed processes and resource impacts (Box 3). These hypotheses may also help further refine the scope and level of assessment necessary to meet project goals. Hypotheses related to issues identified in Figure 1 might include the following:

- Grazing on highly erodible soil contributes the majority of sediment to streams.
- Natural soil erosion causes high turbidity measurements.
- Grazing has altered vegetation communities and increased stream temperatures.
- Erosion from grazing is only a problem on steep slopes near streams.
- Floods are responsible for increased bank erosion.
- Grazing has significantly increased bank erosion and altered aquatic habitat.

If significant changes are proposed in the scope of the Watershed Assessment, it may be necessary to review the issues with all Scoping participants.

Box 3. Generating hypotheses

Generating hypotheses is a vital part of any scientific assessment. Hypotheses can help to determine the required scope of assessment and to focus data collection and analysis on specific objectives. A hypothesis is defined as an assumption that needs verification or proof. Hypotheses are clearly defined statements that can be evaluated during the Watershed Assessment. Data from the assessment can then be used to support or disprove the hypotheses. Often, further data collection and evaluation of competing hypotheses are necessary following the initial Watershed Assessment.

Using a hypothesis to guide the Watershed Assessment

Hypothesis: Grazing has increased the amount of fine sediment on the streambed due to soil compaction and trampling of the streambank.

Level 1 Assessment: The Erosion module identifies soil types that are most susceptible to disturbance from grazing. The Channel module maps bank disturbance from aerial photos. The Aquatic Life module analyzes stream survey data on the percentage of fine sediment in streams.

Level 2 Assessment: The Erosion module quantifies erosion from different land management practices on various soil types. The Channel module quantifies bank erosion using field surveys and predicts sediment transport capacity of streams. The Aquatic Life module identifies potential fish spawning sites and measures fine sediment in the streambed.

Step 2. Identify the assessment team

The assessment team comprises environmental professionals who will use the technical modules or other methods to assess the watershed. For smaller assessments, the team may be composed of just a few local natural resource professionals, but for more complex issues, such as those addressed in a Level 2 assessment, many trained specialists and staff may be necessary (Table 2).

Table 2. Types of specialists to consult for a Level 2 assessment

Module	Profession
Community Resources	Historian, Anthropologist, or Archaeologist
Aquatic Life	Aquatic or Wildlife Biologist
Water Quality	Aquatic Ecologist, Environmental Engineer, Aquatic Biologist, Water Chemist, or Hydrologist
Historical Conditions	Historian or Librarian
Hydrology	Hydrologist or Environmental Engineer
Channel	Geomorphologist, Hydrologist, or Geologist
Erosion	Geologist, Geotechnical Specialist, Soil Scientist, or Geomorphologist
Vegetation	Ecologist or Botanist

Step 3. Conduct assessment team orientation

The composition of the assessment team will depend on the scope of the Watershed Assessment. A team leader is always important to coordinate logistics and to manage the assessment team. The team leader should make sure that assessment team members are acquainted with the watershed (e.g., by distributing maps and environmental reports) and with the WAM process (e.g., by providing copies of the WAM guide or a technical module). The team leader will also be responsible for producing a Watershed Assessment report. Table 3 provides a list of materials that are typically necessary for a Level 1 assessment.

The team leader should organize an initial meeting of the assessment team to do the following:

- Introduce team members.
- Distribute a team contact list.
- Clarify assessment objectives and hypotheses.

Table 3. Typical Level 1 assessment information needs

	Community Resources	Aquatic Life	Water Quality	Historical Conditions	Hydrology	Channel	Erosion	Vegetation
USGS topographic maps	●	●	●	●	●	●	●	●
Watershed base map	●	●	●	●	●	●	●	●
Land use map	●	●	●	●	●	●		●
Ecoregion summary			●	●	●			●
Geology maps					●	●	●	
Soils map			●		●	●	●	●
Slope class map (if GIS available)			●				●	
Aerial photos		●	●	●		●	●	●
Orthophotos					●		●	●
Fish habitat surveys		●				●		
Channel modification information		●		●	●	●		
Mean annual precipitation data					●			
USGS stream gage data		●			●	●		
Existing vegetation maps					●		●	●
National Wetland Inventory (NWI) maps		●						●
Federal Emergency Management Agency (FEMA) floodplain map			●			●		●
Water quality data and reports			●		●			
305 (b) list of state waterbodies			●					
303 (d) list of state waterbodies			●					
Endangered Species Act (ESA) listings or state endangered species		●						
National Pollutant Discharge Elimination System (NPDES) permit compliance data			●					

- Identify sources and availability of watershed data, aerial photos, maps, and environmental reports.
- Assign responsibilities for data collection and analysis (Box 4).
- Discuss assessment product requirements such as maps and reports.
- Establish assessment schedule.
- Note travel issues, such as gate keys, permission for access, and safety.
- Conduct a field tour of the watershed.

Box 4. Emphasizing an interdisciplinary approach

Many of the tasks conducted by individual analysts during the Watershed Assessment will generate useful information for other people on the assessment team. Sharing this information during the assessment will improve each module's evaluation and prepare the team for a productive Synthesis session. Within each technical module, arrow icons like the one shown below identify opportunities for sharing information with other module analysts. Data, preliminary conclusions, and other ideas can be shared using email, information-sharing software, fax, or telephone.

During the team orientation, it will be helpful to delineate sub-basins together so that areas of special interest can be analyzed at a similar scale. The assessment team should also discuss opportunities for joint data collection (e.g., stream surveys to collect data for the Water Quality, Aquatic Life, Channel, and Hydrology modules).

Step 4. Conduct assessment using technical modules

Each module analyst should review the appropriate technical module and customize the methodology as necessary to address the specific watershed issues and project goals identified during Scoping. The technical modules are located in the final sections of this guide.

The assessment team leader should periodically monitor the progress of the Watershed Assessment. The team leader may need to ensure that information sources are being shared and dialogue and interaction are occurring among team members. If GIS is being relied upon for analyses or map production, the team leader should coordinate regularly with the GIS specialist(s) to ensure a smooth and efficient transfer of information.

Step 5. Conduct pre-Synthesis assessment team meeting

A meeting of the assessment team prior to beginning the more formal Synthesis process is usually helpful to accomplish the following:

- Discuss interim findings and conclusions.
- Refine hypotheses based on shared information.
- Identify further assessment work needed.
- Review schedule and objectives.

Technical module analysts should be prepared with preliminary maps, tables, and graphs to summarize their findings. Preparing this material prior to Synthesis helps to organize the assessment results and identify gaps in information. Most of the material can also be used during Synthesis and in the Watershed Assessment report.

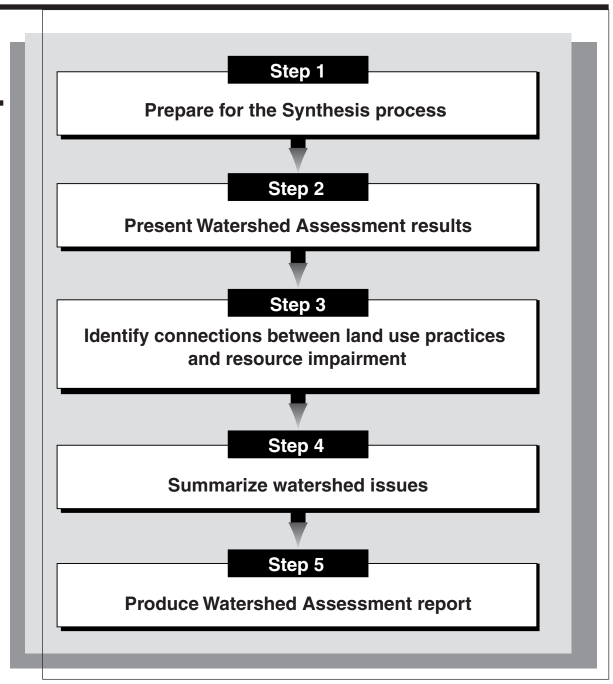
Step 3: **Synthesis**

Introduction

The Synthesis step of the WAM process provides an opportunity for interaction among the assessment team members to provide a more comprehensive picture of the watershed. Synthesis is generally an interdisciplinary evaluation involving a larger assessment team, but even smaller assessment teams can summarize and evaluate the information in an interdisciplinary fashion. These discussions often lead to new insights about important watershed processes and the status of community resources.

Synthesis Process

Step Chart



Procedure

The objectives of the Synthesis step are as follows:

- To share information generated from various areas of the assessment.
- To identify important interactions among land uses, watershed processes, and community resources.
- To summarize key watershed issues to be addressed in the Management Solutions step.
- To determine potential future actions for key watershed issues (e.g., Level 2 assessment, management practices, restoration plans, monitoring plans).

Step 1. Prepare for the Synthesis process

The Synthesis process is typically organized and facilitated by the assessment team leader. The assessment team members are the primary participants, but other community members may also be interested in following the process. The team leader will need to notify potential participants and schedule Synthesis meetings. Synthesis meetings may last from two days to a few weeks, depending on the complexity of watershed issues and the scope of the assessment. If more than two to three days will be required to complete the Synthesis process, it is advisable to spread out the meetings over two to three weeks. A break between Synthesis sessions is important not only to maintain the focus of the participants but also to allow for follow-up work to address questions raised during Synthesis or to fine-tune the assessment.

At the Synthesis meetings, the assessment team members should be prepared to present the results of their respective assessments along with appropriate maps. The checklist provided in Box 1 summarizes the important products from each WAM technical module. Depending on the scope of the assessment, some of these products may not have been created. Ideally, the analysts would have a draft of their module reports completed. Writing draft reports prior to Synthesis ensures that critical work has been completed and helps identify information needs and potential linkages with other modules. Completion of maps and forms will help make the Synthesis meetings effective and efficient.

A number of general Synthesis questions that may need to be addressed by each module are presented in Box 2. These questions illustrate the types of issues addressed by the Synthesis process and may not be appropriate for all watershed assessments.

Step 2. Present Watershed Assessment results

If some Synthesis participants are unfamiliar with the WAM process, the team leader should orient participants on the purpose of the Watershed Assessment, the issues identified in Scoping that were investigated by the assessment team, and the role of Synthesis meetings in the WAM process.

Box 1. A checklist of module products needed for Synthesis

Module	Products
Community Resources	☐ Map CR1. Community resources
	☐ Form CR1. Categorization of community resources
	☐ Form CR2. Trends in community resource conditions
Aquatic Life	☐ Map AL1. Aquatic species distribution
	☐ Map AL2. Aquatic habitat distribution
	☐ Map AL3. Aquatic habitat conditions
	☐ Form AL1. Summary of hypotheses
Water Quality	☐ Map WQ1. Water quality impairments
	☐ Form WQ1. Summary of water quality conditions
Historical Conditions	☐ Map HC1. Historical sites
	☐ Form HC1. Historical timeline
	☐ Form HC2. Trends in watershed resource conditions
Hydrology	☐ Map H1. Water control structures
	☐ Form H1. General watershed characteristics
	☐ Form H2. Summary of hydrologic issues by sub-basin
Channel	☐ Map C1. Channel segments
	☐ Map C2. Geomorphic channel types
	☐ Form C1. Historical channel changes
	☐ Form C2. Geomorphic channel type characteristics
Erosion	☐ Map E1. Land types
	☐ Form E1. Summary of erosion observations
	☐ Form E2. Summary of land type characteristics
Vegetation	☐ Map V1. Upland vegetation
	☐ Map V2. Riparian/wetland vegetation
	☐ Map V3. Land use practices that affect vegetation
	☐ Form V1. Vegetation category summary

Box 2. Synthesis questions

Community Resources

- What are the ecological needs of community resources relative to hydrology, erosion, stream conditions, vegetation, and water quality?

Aquatic Life

- What are the habitat requirements of aquatic life in the watershed?
- How is aquatic life affected by interactions among erosion, hydrology, riparian function, water quality, and stream channel processes?
- How is the distribution of aquatic species influenced by natural conditions?

Water Quality

- How have resources in the watershed been affected by pollutants?
- How do natural conditions in the watershed influence water quality in various waterbodies?
- How do natural conditions in the watershed influence the transport and fate of pollutants in the watershed?
- How have land use practices influenced water quality conditions in the watershed?

Historical Conditions

- When have land use/management changes altered watershed conditions?

Hydrology

- How do climate, geology, and topography influence surface and sub-surface water flow through the watershed?
- How has land use altered the flow of water through the watershed?
- How have alterations in the flow of water influenced conditions for resources?

Channel

- How do watershed climate, geology, and topography influence runoff, sediment transport, and aquatic habitat conditions?
- How do channel conditions influence physical and biological processes in the streams?

Erosion

- How do the climate, geology, and topography of the natural landscape influence sediment generation and transport in the watershed?
- How do land use activities change the frequency and magnitude of erosion at a watershed scale?
- How have alterations in the flow of water influenced conditions for resources?

Vegetation

- How have vegetation communities changed over time, and what has caused these changes?
- What riparian and wetland functions are important for protecting aquatic habitat, water quality, or other community resources?

The first day of Synthesis meetings is typically devoted to presentations of information gathered by the assessment team. Presentations should be tailored to the knowledge and experience of the participants in the Synthesis meeting (Box 3). After each presentation, additional time will typically be required to discuss the findings and consider information from other module analysts. The total time for each module presentation and discussion should be no more than one hour so that all the presentations can be completed in a day.

Box 3. Assessment team presentations

Each module analyst should present the following information:

- Module objectives and critical questions.
- A brief description of materials and methods.
- A summary of results using maps, figures, and tables.
- A discussion of the findings and the relationship to other modules.

Step 3. Identify connections between land use practices and resource impairment

After the first day of assessment team presentations, the Synthesis meetings should focus on outlining the linkages between modules and summarizing watershed issues. Depending on the complexity of watershed issues, the amount of available information, and the size of the watershed, this step may require from one to several days to complete.

Outlining potential connections among land use practices, watershed processes, and community resources can be approached from a number of angles. In a Level 1 assessment, starting with a resource is typically a good way to begin developing potential explanations or hypotheses for impairment (Box 4). Information from various modules can provide insight on the potential for delivery of hazardous inputs or the influence of natural conditions on the state of the resource. The Synthesis group should work together in developing various hypotheses and identifying the most promising hypotheses as watershed issues.

Hypotheses should be scrutinized based on the following:

- An evaluation of plausible alternatives.
- Existence of supporting scientific data.
- Different lines of supporting evidence.
- The ability of factors to amplify or attenuate an effect.

Box 4. Identifying connections between an impaired resource and land use practices, an example from the Penobscot River basin, Maine

Step 1. Identify Impaired Beneficial Resource
One of the critical issues in the Penobscot River basin, Maine, is a fish consumption advisory due to contamination with mercury, dioxin, and PCBs. Fish are an important cultural resource for the Penobscot Indian Nation, and angling is an important recreational activity for the entire watershed community.

Step 2. Identify Potential Sources of Impairment
Potential sources of these pollutants include discharge of wastewater from paper mills, contaminated sediments in the Penobscot River, aerosol deposition from industrial smokestacks, and naturally occurring mercury-bearing rocks.

Step 3. Identify Relevant Watershed Processes and Data Needs
Water chemistry data are important for identifying potential point source discharges. Stream sediment composition, pollutant load, and transport characteristics are important data to determine the significance of this source of pollutants. Geology information may also be crucial for identifying potential natural sources of mercury. Since fluctuating water levels allow mercury to be methylated and thus susceptible to uptake by biological organisms, information on changes in streamflow and dam operations may also be important.

Step 4. Identify Promising Hypotheses and Information Gaps
Point source discharges of pollutants from wastewater and smokestacks are the most likely sources of impairment. Little information exists on contaminated sediments and the potential for biological uptake, but this is potentially an important source. A review of geologic data revealed that rocks in the area contain minimal amounts of mercury.

Evaluating hypotheses will help to identify gaps in knowledge, increase confidence in cause-and-effect relationships, and prioritize future actions.

The Synthesis group may find that in some cases it is easier to develop hypotheses around a landscape sensitivity or land management practice. Landscape sensitivities might include a landform that is particularly susceptible to erosion or a vegetation community that is easily disturbed. Land management practices that are consistently causing problems can also be the focus of a hypothesis. For example, forest road construction within 100 feet of streams may consistently cause sedimentation problems, or stormwater discharge into shallow lakes may cause an increase in algae bloom size and duration.

Step 4. Summarize watershed issues

Watershed issues can be categorized in three general ways: 1) by community resource, 2) by hazardous input (e.g., pollutant), or 3) by land use practice (Box 5). Categorizing watershed issues is a subjective process, but it is important to provide detailed information on the issues in a form that the Scoping participants and the management team can understand and use to make decisions. The following details should be provided for each issue:

- The management activities potentially causing impairment.
- The location of hazardous inputs.
- The location of sensitive resources.
- The mechanism of impairment.
- Data and other evidence to support conclusions.

At this point, it will be helpful to review the issues identified during Scoping in light of the Watershed Assessment and the discussion of hypotheses. Based on this discussion, general watershed issues identified during Scoping may need modification to better reflect current knowledge or to highlight specific concerns. New watershed issues may also be identified.

Box 5. Organizing watershed issues, example from the Penobscot River basin, Maine

The Penobscot River basin has a number of beneficial resources impacted by point source discharge of pollutants such as PCBs, dioxin, and mercury (Box 4). The issue of mercury loading is sufficiently complex and different from the other pollutant issues to merit consideration on its own. While impairment of resources was the focus of initial discussions, the watershed issues in this case were more logically organized according to the hazardous inputs: 1) PCBs and dioxin, and 2) mercury.

Form S1 provides a template for summarizing important watershed issues (Box 6, Figure 1). Form S1 is one of the primary products of the Synthesis process and will be a key element of the last two WAM steps: Management Solutions and Adaptive Management. The following paragraphs describe each element of Form S1 in further detail.

Box 6. Information to include in Form S1. Summary of watershed issues

Watershed Issue:	Community Resource, Hazardous Input, or Land Use Practice
Location:	Sub-basin, Stream Segment, Waterbody, or Landform (reference maps and figures as necessary)
Situation Summary:	Input from Watershed, Time Frame, Watershed Process, Hazard Location, Management Activity, Delivery Conditions, Sensitive Resource Location, Channel and Resource Effects
Recommendations:	Level 2 Assessment, Management Changes, Restoration Plan, or Monitoring Plan
Justification:	Supporting Data, Criteria for Resource Sensitivity, Delivery Potential, Confidence in Assessment

Watershed Issue: The community resource, hazardous input, or land use practice that is the focus of the issue should be clearly identified.

Location: The area affected by the particular watershed issue should be referenced as specifically as possible. The location may be as large as the entire watershed or a sub-basin or as specific as one stream segment or landform. Reference appropriate maps to help people who are unfamiliar with the watershed or who did not participate in the assessment.

Figure 1. Sample Form S1. Summary of watershed issues

Watershed Issue: Soil Erosion

Location: Erosion Units 1 and 2 (Map E1) in the Bear Creek and Crazy Creek sub-basins.

Situation Summary:
Soil erosion is a problem in Erosion Units 1 and 2 due to disturbance of erodible soils from 1) road construction, 2) rerouting of water drainage from paved surfaces, 3) compaction of soil from grazing, and 4) natural erosional processes (weathering, soil creep, dry ravel, bank erosion). Sediment delivery to streams generally occurs within 75 feet of waterbodies. Most of the problems occur in low-gradient, moderately-incised streams in loess deposits (Channel Type 8). The accumulation of fine particles affects fish and aquatic plants by 1) reducing egg to fry survival for fish by cementing gravel and reducing the flow of oxygen, and 2) preventing the growth of snake reeds, which are an important tribal resource for basket-weaving and traditional medicine.

Recommendations:
1. Work with rural residential and forest landowners to develop options for reducing sediment delivery from gravel roads.
2. Work with the County Land Development and Engineering department to improve current and future water drainage structures and storm runoff detention.
3. Develop grazing management plan to reduce streambank trampling and to revegetate riparian corridors.
4. Conduct a Level 2 assessment to better quantify the sources of erosion.
5. Monitor the percentage of fine sediment before and after implementation of BMPs.

Justification:
Field observations, anecdotal information, and stream surveys provide evidence for the erosion problems in these two land types. Gant et al. (1999) and unpublished tribal and county reports provide more detailed examples of problems. While a high level of fine particles probably existed naturally in streams running through these loess deposits, land management practices have visibly increased their volume. A level of 30% fines or higher was considered a problem based on habitat requirements for fish. A high level of confidence exists in identifying the causes for erosion because of its broad documentation. A Level 2 assessment, however, would help to quantify each source of erosion and thus help in prioritizing and justifying management solutions.

Situation Summary: The situation summary describes the watershed problem in a simple and structured fashion (Box 7). The basic elements of the situation summary are provided in Box 6 and are illustrated in Box 8.

Box 7. Developing situation summaries

Development of situation summaries can be a time-consuming process that requires focused writing and editing. While these summaries rely on information from several different modules, it may be desirable to have one individual or group of individuals produce initial drafts of the situation summaries outside of the Synthesis meetings. Rather than spending the entire group's time describing each watershed issue in detail, the Synthesis meetings can then be more effectively used to critique and modify the draft situation summaries.

Box 8. Sample situation summary

Input from Watershed	Fine sediment
Time Frame	from past and potential future
Watershed Process	soil erosion in
Hazard Location	Erosion Units 1 and 2
Management Activity	due to 1) disturbance of erodible soils from road construction, 2) rerouting of water drainage from paved surfaces, 3) compaction of soil from cattle grazing, and 4) natural erosional processes (weathering, soil creep, dry ravel, bank erosion)
Delivery Conditions	within 75 feet of streams and wetlands
Channel Effects	has caused and/or could cause accumulation of fine particles
Sensitive Resource Location	within low-gradient, moderately-incised channel types in loess deposits (Channel Type 8)
Resource Effects	that can 1) reduce egg to fry survival for fish by cementing gravel and reducing the flow of oxygen and 2) prevent the growth of snake reeds, which are an important tribal resource for basket-weaving and traditional medicine.

Recommendations: The quality of data available for the Watershed Assessment, the assessment scale or level of detail, and the confidence in conclusions drawn from the assessment will all influence potential recommendations (Box 9). The intent of making recommendations is to provide guidance for future steps rather than to develop specific management solutions. Management solution development will occur in the next step of the WAM process.

Box 9. Confidence in recommendations

Lack of quality data or confidence in the assessment results should lead to further study in the form of a Level 2 assessment or longer-term monitoring. Strong evidence for cause-and-effect relationships is required to recommend management changes or restoration plans.

Justification: Providing evidence for conclusions from the Watershed Assessment is one of the most important exercises in the Synthesis process. Sources of data or other evidence should be referenced to support the situation summary. The standards or criteria used to rate landscape hazards, resource sensitivities, and delivery potentials should be clearly described. Finally, confidence in the assessment and conclusions should be discussed. A High/Moderate/Low rating can be used to assess confidence, but the summary should also provide explanations for each rating (Box 10).

Box 10. Confidence summaries

Rating confidence in the assessment and conclusions should be based on the following:

- The availability of information.
- The quality of information.
- The ability to analyze and interpret the data.
- The lack of alternative explanations.

Step 5. Produce Watershed Assessment report

The assessment team leader is typically responsible for producing an overall Watershed Assessment report. The format for this report is flexible, but the report should provide easily accessible information to community members. In most cases, a concise report will be more effective in communicating watershed issues than will a complex technical document with extensive data. Striking a balance between the need to communicate effectively with a potentially diverse audience and the need to provide scientific documentation to support conclusions is one of the greatest challenges in creating a useful Watershed Assessment report.

While each module analyst should have a short report on assessment results, the team leader must synthesize this information to provide a comprehensive picture of watershed conditions. This comprehensive picture can be effectively presented as the watershed story, a narrative that describes historical conditions and evaluates the effects of changes over time. The format of the Watershed Assessment report is flexible, but the report should describe important results and conclusions in a succinct manner (Box 11). The maps, tables, and forms produced in each module are designed to provide concise summaries of results as well as logic tracking for quality assurance and control.

Box 11. Example outline for a Watershed Assessment report

I. **Introduction**
   A. Purpose/objective of assessment
   B. List of sponsors and participants
   C. Watershed issues
   D. Regulatory or policy issues
II. **Description of Watershed**
   A. Location, size, ownership, and land uses
   B. Topography, geology, soils
   C. Climate
   D. Streams, sub-basins, waterbodies
   E. Vegetation
   F. Historical land uses and disturbances
III. **Summary of Watershed Assessment**
   A. Watershed story
   B. Summary of issues
   C. Recommendations
   D. Research and monitoring needs
   E. Confidence in assessment
   F. Quality assurance and control
IV. **Technical Module Reports**
   A. Community Resources
   B. Aquatic Life
   C. Water Quality
   D. Historical Conditions
   E. Hydrology
   F Channel
   G. Erosion
   H. Vegetation

Form S1. Summary of watershed issues

Watershed Issue:
Location:
Situation Summary:
Recommendations:
Justification:

Step 4: **Management Solutions**

Introduction

The goal of the Management Solutions step is to create a watershed management plan to address the issues identified during Scoping, Watershed Assessment, and Synthesis. The management plan should describe multiple management solutions to provide flexibility in the implementation of watershed improvements (Box 1).

Management solutions for addressing watershed issues or problems can take many forms:

- Changes in land use (e.g., land use planning or zoning).
- Changes in management practices (e.g., Best Management Practices [BMPs]).
- Monitoring programs.
- Educational programs.
- Restoration plans.
- Regulatory changes (e.g., water quality standards and criteria).

Box 1. Watershed management planning in Nantucket, Massachusetts

In response to a variety of threats to Nantucket's water supply, the Nantucket Land Council, a private, non-profit organization, commissioned the development of a water resource management plan. Twelve water resource protection areas were delineated as part of the plan and designated for priority protection. Among these areas were well-head protection areas for the island's two principal public water supply wells, a larger aquifer protection area designated as a source of future water supplies, and the drainage areas for coastal and freshwater ponds. The designated areas were protected by a combination of regulatory and non-regulatory measures, including zoning districts that regulated land use, subdivision and wetlands regulations, on-going water quality monitoring, and public education campaigns discussing the residential use of lawn fertilizer and household chemicals.

Adapted from EPA (1995a)

The type of management solutions developed through the WAM process will depend largely on the scale and level of assessment. A Level 1 assessment provides a general characterization of the watershed that may be useful for land use planning, identifying monitoring needs, or developing educational programs. This level of information is typically not detailed enough to evaluate or suggest specific prescriptive actions. A Level 2 assessment can provide more site-specific information that can be used to evaluate the effectiveness of management practices, identify restoration opportunities, or establish resource-based water quality standards.

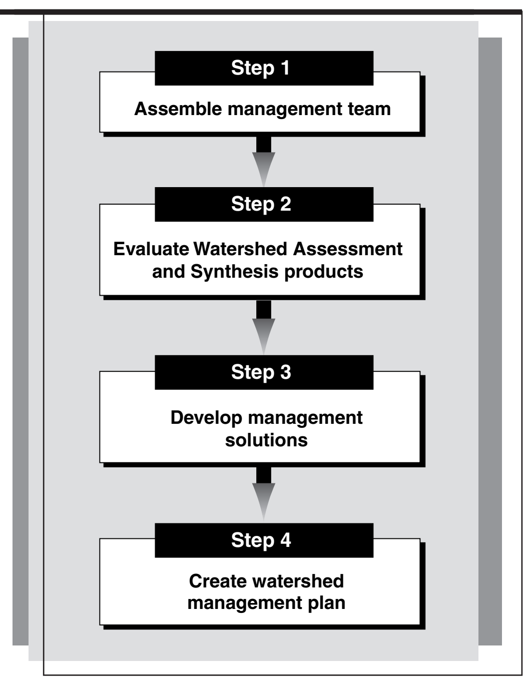
Using information generated during the previous steps, the WAM approach can provide a strong link between community values, scientific information, and the development of practical and effective management solutions. Information from these steps is used to identify resource needs, the effects of current and past management, and the success or failure of past practices. With broad community participation and support, the technical information can be used to suggest effective management changes to protect and enhance the valued resources identified during the Scoping process.

Watershed management plans should be integrated with existing programs and tailored to the needs of the community and the unique character of the watershed. Ideally, multiple programs and solutions will be developed as part of the management plan to provide flexibility in the implementation of watershed improvements. Existing projects and programs such as water quality monitoring or stream restoration should be considered elements of a comprehensive watershed approach to management solutions.

This section describes the steps to develop a watershed management plan. Examples of management objectives and solutions are provided. Information on watershed restoration is described, and possible sources of funding are identified. Information on developing monitoring programs can be found in the next section, Adaptive Management.

Management Solutions Process

Step Chart



Procedure

The objectives of the Management Solutions step are as follows:

- To use information from previous steps to develop management objectives and options.
- To create a watershed management plan.
- To develop incentives for implementation of management solutions.

Step 1. Assemble management team

The management team will be responsible for setting management objectives and developing a set of prioritized options for each objective. Deciding who will participate on the management team depends upon the number of people involved in the WAM process. If a small number of people are involved, it may be possible to include all participants in the management team. Otherwise, a cross-section of community leaders and technical staff should be included on the management team. If effective changes are expected from this process, it is vital to include representatives from all interested parties who might be affected by the proposed management changes.

A combination of people with technical and policy backgrounds in environmental resource management is ideal to identify and evaluate options for changes in management practices and watershed programs. At least a few individuals who participated in the Watershed Assessment can be a part of the management team to provide background information and help resolve technical questions. Land owners, industry representatives, and regulatory agencies may also be integral for developing effective management solutions.

Step 2. Evaluate Watershed Assessment and Synthesis products

Before management objectives and solutions can be written, it is important to understand the results of the Watershed Assessment and the summaries of watershed issues that were produced in Synthesis (Form S1). The summaries of watershed issues may provide sufficient detail for establishing objectives and solutions, but often a more comprehensive understanding of watershed issues is necessary. If the management team is identified ahead of time, it may be helpful for members to attend the Synthesis meetings. Another option is for the assessment team to provide a summary presentation to the management team. A field review of the watershed or specific areas of concern may also be warranted to provide further information for developing effective management solutions.

Step 3. Develop management solutions

The summaries of watershed issues (Form S1) from Synthesis provide a list of watershed concerns that may require specific management solutions. The team should develop a management objective for each issue. A set of specific solutions can then be written to address each objective. Multiple options are encouraged for each objective to provide flexibility for implementation by community members (Box 2). The objectives and solutions should be recorded on Form M1 (Figure 1). The rationale for each solution should also be recorded for future reference. Rationale may be based on local data, technical and management expertise, or scientific literature.

Box 2. Management planning in the Klamath River basin, Oregon

Physical obstructions, habitat destruction, and pollutants have severely degraded an important tribal and commercial salmon and trout fishery in the Klamath River, Oregon. The long-range restoration plan was developed using a sequence of goals, objectives, policies, and priority projects. Examples of goals, objectives, and policies from this program are provided below.

Goal: Restore by 2006 the biological productivity of the basin in order to provide for viable commercial and recreational ocean fisheries and in-river tribal and recreational fisheries.

Objective: Protect stream and riparian habitat from potential damage caused by timber harvesting and related activities.

Policies:

- Improve timber harvest practices through local workshops; develop habitat protection and management standards for agency endorsement; and create a fish habitat database.
- Evaluate current timber harvest practices by developing an index of habitat integrity; incorporating fish habitat and population data into state water quality assessments; and monitoring recovery of habitat in logged watersheds.
- Promote necessary changes in regulations, including state forest practice rules, USFS policies in land management plans, and BMPs.
- Anticipate potential problems by requesting additional state monitoring programs; modifying state and federal rules to protect erodible soils; and giving priority to protection of unimpaired salmon habitat.

Adapted from Klamath River Basin Fisheries Task Force (1991)

Figure 1. Sample Form M1. Summary of management options

Issue	Management Objective	Management Solutions	Cost Estimate	Rationale
Erosion from gravel roads	Minimize delivery of eroded sediment to streams	1. Install additional culverts. 2. Grass-seed road cut and fill slopes. 3. Voluntary traffic management plan.	1. $20,000 2. $5,000 3. $1,000	Past use of road improvement plans has been effective at substantially reducing sediment delivery to streams.
Untreated wastewater delivery to the Massassaqua River	Minimize delivery of dairy farm waste to streams during floods	1. Create additional waste storage ponds. 2. Relocate waste storage ponds outside of 100-year floodplain. 3. Establish vegetated biofiltration drainage features.	1. $200,000 2. $75,000 3. $20,000	The watershed assessment identified the close proximity of waste storage facilities to streams as the primary factor causing elevated fecal coliform levels in the river.
Protection of unique natural areas for recreation and wildlife habitat	Restore natural prairie and riparian vegetation communities	1. Initiate educational program on value of riparian buffers. 2. Establish pilot projects for vegetation restoration. 3. Develop conservation easements with private landowners.	1. $5,000 2. $35,000 3. $100,000	The watershed assessment indicated that natural prairie and riparian communities could be re-established through the use of buffers and restoration techniques.
Pollutants in drinking water	Identify trends in drinking water quality	1. Expand existing water quality monitoring program with three additional stations. 2. Conduct statistical analysis and produce a summary report for water quality data from past 10 years of monitoring.	1. $12,000 2. $10,000	Water quality data have been collected at a few locations, but no summary or evaluation of trends has been completed.

Land management options

Table 1 provides examples of management objectives and options to minimize aquatic impact from various land uses. The key to effective aquatic resource protection often is to use several types of aquatic management practices in concert with education and, as necessary, regulation (EPA 1995a). A single type of management practice is seldom sufficient to solve watershed-scale problems. A number of sources are available that provide ideas and guidance on the use of various management solutions:

- Agriculture
  - EPA (1984) describes the factors and available research relevant to selecting appropriate pesticide BMPs.
  - The National Agricultural Library (***http://warp.nal.usda.gov***) offers a bibliography of over 300 citations on evaluation of agricultural BMPs from the AGRICOLA database. The NRCS also provides the National Handbook of Conservation Practices (***http://www.nrcs.usda.gov***) to provide established standards for commonly used practices to protect natural resources.
  - Local NRCS offices often have Field Office Technical Guides at the county level for watershed-specific information.
- Urban
  - Metropolitan Washington Council of Governments (1990) lists non-point source control techniques for urban areas.
  - EPA (1994) describes institutional strategies for developing, revising, and implementing runoff control programs in urbanized communities.
  - EPA (1990) provides information on targeting and prioritizing BMPs in urban areas.
- Forestry
  - EPA (1993a, 1993b) provide a synopsis of BMPs used to mitigate impacts on water quality caused by forestry operations.
- Wetlands
  - EPA (1996) is a guide to stormwater BMPs for protecting wetlands in urban areas, but many practices would also be applicable in other settings.
- Coastal Waters
  - EPA (1992a) describes appropriate management measures and management practices for each major category of non-point source pollution (agriculture, forestry, urban, etc.).

Table 1. Examples of management options and solutions

Land Use Issue	Management Objectives	Management Options
Confined Animal Facilities (small units)	• Design and implement systems that collect solids, reduce contaminant concentrations, and reduce runoff to minimize delivery of pollutants. • Reduce groundwater pollutant loading. • Manage stored runoff and accumulated solids through an appropriate waste utilization system.	• Waste storage ponds • Waste storage structure • Waste treatment lagoons • Filter strips • Grassed waterways • Constructed wetlands • Dikes • Diversions • Heavy use area protection • Lined waterways/outlets • Roof management systems • Terraces • Composting facilities
Forestry	• Establish Streamside Management Areas (SMAs) along surface waters with appropriate widths and harvest restrictions to: 1. maintain a natural temperature regime; 2. provide bank stability; 3. minimize delivery of sediments and nutrients to streams; 4. provide trees for a sustainable source of large woody debris needed for channel structure and aquatic species habitat; and 5. minimize wind damage. • Specify BMPs to minimize erosion. • Develop Road Management Plans.	• SMAs can vary greatly in width depending on site-specific factors (e.g., slope, class of watercourse, type of soil and vegetation, and practice). • Minimize disturbance in SMA from heavy machinery that could expose the mineral soil of the forest floor. • Locate landings, sawmills, and roads outside the SMA. • Establish buffers for pesticide and fertilizer application to limit entry into surface waters. • Prevent excessive amounts of slash and small organic debris from entering the waterbody. • Apply harvesting restrictions in the SMA to maintain its integrity.
Agricultural Land	• Minimize the delivery of sediment from agricultural lands to surface waters. • Design and implement a combination of management practices to settle fine-grained solids and associated pollutants to minimize delivery to streams.	• Conservation cover on land retired from production • Conservation cropping sequence • Conservation tillage • Contour farming • Cover and green manure crop • Plantings on erodible or eroding areas • Leave crop residue to provide protection from erosion • Delayed seed bed preparation • Field border or other filter strip • Grassed waterways • Grasses and legumes in rotation • Sediment basins • Field strip-cropping • Terracing • Wetland and riparian zone protection

Adapted from EPA (1992a)

Restoration approaches

Understanding the relationships among physical, chemical, and biological watershed processes is critical for determining where and what type of habitat restoration will be effective for improving stream quality and supporting valued resources. Since most restoration projects are relatively expensive, the longevity and cost-effectiveness of the project must be objectively evaluated.

Stream restoration can be categorized by three general approaches (EPA 1995b):

1. Upland techniques generally involve BMPs that control non-point source inputs from the watershed (e.g., erosion and runoff control, reforestation, restoration of native plant communities, wetland restoration).
2. Riparian techniques are applied out of the channel in the riparian corridor (e.g., reestablishment of vegetative canopy, increasing width of riparian corridor, restrictive fencing).
3. In-stream techniques are applied directly in the stream channel (e.g., channel realignment to restore geometry, meander pattern, substrate composition, structural complexity, or streambank stability).

In-stream restoration practices often need to be accompanied by techniques in the riparian area and the surrounding watershed. For example, restoring a stream may not only involve reconfiguring the channel form and stabilizing stream banks but can also require planting riparian vegetation and controlling excess sediment and chemical loading in the watershed. Details about specific restoration practices are beyond the scope of this guide; however, Table 2 provides examples of techniques relevant to various watershed issues.

The following sources provide further information on restoration strategies and techniques:

- Streams
  - *The Restoration of Rivers and Streams: Theories and Experience* (Gore 1985).
  - *Better Trout Habitat: A Guide to Stream Restoration and Management* (Hunter 1991).
  - *A Classification of Natural Rivers* (Rosgen 1994).
  - *Ecological Restoration: A Tool to Manage Stream Quality* (EPA 1995b).

Table 2. Examples of restoration techniques for various watershed issues

Watershed Issue	Restoration Technique
Altered Stream Morphology	• In-stream structures (e.g., logs, boulders) • Bank protection • Promote riparian vegetation growth
Sedimentation	• Reduce sediment delivery • Restore wetlands • Stabilize banks • Modify operations of water diversion structures
High Streamflows	• Restore natural stream meanders and complexity • Increase substrate roughness • Promote riparian vegetation growth • Restore wetlands • Reduce impervious area
Low Streamflows	• Reduce water withdrawals • Restore native riparian vegetation • In-stream structures (e.g., logs, boulders) • Increase channel depth with machinery • Stabilize banks • Reduce sediment delivery • Restore native riparian vegetation
Biological Integrity	• In-stream structures (e.g., logs, boulders) • Remove passage barriers (e.g., diversions, culverts) • Reduce sediment delivery • Dredging
Toxicity	• Capping material • Restore wetlands for filtering • Promote riparian vegetation growth
Water Temperature	• In-stream structures (e.g., logs, boulders) • Reduce water withdrawals

- Riparian Corridors
  - *Stream Corridor Restoration: Principles, Processes and Practices* (Federal Interagency Stream Restoration Working Group 1998).
  - *A Citizen's Streambank Restoration Handbook* (Izaak Walton League 1995).
- Wetlands
  - *Restoration of Aquatic Ecosystems* (Brooks et al. 1992).
  - *Wetland Creation and Restoration: The Status of the Science* (Kusler and Kentula 1990).

Step 4. Create watershed management plan

Unless the watershed group is small, the management options detailed in Form M1 will generally require review and prioritization by a group of community members larger than the management team alone. This group, often the same people involved in the Scoping step, will need to evaluate management options to ensure that they have community support and the appropriate resources to be implemented. The approved management solutions will be incorporated into a final watershed management plan that prioritizes watershed actions over the next 10 to 20 years (Box 3).

Box 3. Key elements of a watershed management plan

- Clearly defined management objectives
- Range of management options
- Prioritization of management solutions
- Description of rationale and uncertainties
- Cost estimates and funding mechanisms
- Schedule for implementation and completion

The watershed management plan should relate directly to the strategy developed in the Scoping process. The watershed management plan typically involves more specific actions than the strategy developed in Scoping but should be consistent with the WAM goals. In some cases, the watershed management plan may actually become the new watershed strategy.

Prioritizing management actions can be based on any combination of criteria, including the following:

- Expected benefit to resources.
- Geographical importance.
- Critical or unique areas.
- Potential threat to resources.
- Financial impact.
- Community support.

Integrating the scientifically-based watershed priorities with community priorities is one of the biggest challenges of the WAM process. Management options may be prioritized initially based on the technical merits of the proposal, but community values may lead to different priorities. Gaining community support to conduct projects in the highest priority areas may require initially working in biologically less important areas. Projects that engage local community support can then be used to educate the community about working in higher priority areas even if the project is not in close proximity. Working in a lower priority area may also serve as a pilot project to help learn about potential issues and problems that could arise on a bigger and higher priority project.

Along with the prioritized management solutions, the watershed management plan should include the rationale for choosing priorities or projects. A schedule for the implementation and completion of management actions is also an important component of the plan. Finally, the watershed management plan should be clearly summarized so that the community can easily understand the rationale and outcomes of implementing the plan.

Incentives for implementation

It may be difficult to reach consensus on some management solutions. Management solutions may benefit society as a whole but may not provide an economic benefit to the individual or organization responsible for implementing them. The limited understanding of ecosystems may lead to uncertainties about the results of the assessment. Community members may also disagree about the risk to important resources posed by management practices. Some may argue for the least costly methods, others for the most effective methods, regardless of cost. It will be important to consider incentives for participation and voluntary, rather than regulatory, implementation of BMPs (Box 4). Table 3 summarizes potential incentives to consider in a watershed management plan.

Box 4. Cooperation and incentives in a community context

Most discussions of land management activities will involve personal communication with a land manager, private landowner, or government representative. Cooperative projects, cost-share programs, and technical assistance will probably be the most commonly used incentives. Community meetings and discussions will generally be more productive than will regulatory mechanisms for achieving watershed recovery.

The White Mountain Apache Tribe in Arizona was able to educate local ranchers about the need to protect springs and streams important to the tribe. The tribe hired members of the local livestock association to construct fencing around restoration areas. The investment of time and money by local community members will help to ensure the long-term success of these projects.

Table 3. Incentives for implementing management solutions

Type of Incentive or Motivational Factor	Description of Key Factors
Education	Programs that target and tailor the message to key audiences are most effective in causing change. Technical education about operation and benefits of controls may be necessary.
Technical assistance	Through one-on-one interaction with landowners, the professional staff can recommend appropriate BMPs for various sites. Assistance with on-site engineering or agronomic work may be needed during the implementation of management solutions.
Tax advantages	Federal, state, or local taxing authorities can make changes to reward individuals who implement management solutions.
Cost sharing	Direct payment to individuals who implement management solutions has been effective where the cost-share rate is high enough to elicit widespread participation.
Regulatory incentives	A regulatory system can be established that conditions the receipt of benefits on meeting certain requirements or goals.
Direct purchase of sensitive or problem areas	The purchase of land for preservation, such as community-owned greenbelts or critical wildlife habitat, can be managed by groups such as the Nature Conservancy. Costs are generally high, but direct purchase provides effective protection.
Non-regulatory site inspections	A site visit by staff of local or state agencies can be educational and provide an incentive for voluntary implementation of management solutions.
Community pressure	If a community values the use of certain management solutions, land owners and managers are more likely to implement them.
Direct regulation of land use activities	Regulatory programs that are simple, direct, and easy to enforce are quite effective. Such programs can regulate land use (through zoning ordinances) or the kind and extent of activity allowed (e.g., pesticide application rates), or they can set performance standards for a land activity (such as retention of the first inch of runoff from urban property).

Adapted from EPA (1995a)

Funding
Funding is usually the greatest limitation to watershed management improvements, but well-organized plans using the WAM approach should be eligible for many types of private and public grants. With a little effort, sources of money can be pooled to implement a watershed management plan. The following references are helpful for procuring funds:

- EPA (1999) presents information on 52 federal funding sources (grants and loans) that may be used to fund a variety of watershed protection projects. The information on funding sources is organized into categories, including coastal waters, conservation, economic development, education, environmental justice, fisheries, forestry, Indian tribes, mining, pollution prevention, and wetlands.

- EPA (1992b) describes particularly effective state and local non-point source programs and methods used to fund them.

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Form M1. Summary of management options

Issue	Management Objective	Management Solutions	Cost Estimate	Rationale

Step 5: Adaptive Management

Introduction

Adaptive management is the process by which new information about the health of the watershed is incorporated into the watershed management plan. Adaptive management is a challenging blend of scientific research, monitoring, and practical management that allows for experimentation and provides the opportunity to "learn by doing." It is a necessary and useful tool because of the uncertainty about how ecosystems function and how management affects ecosystems. Adaptive management requires explicit consideration of hypotheses about ecosystem structure and function, defined management goals and actions, and anticipated ecosystem response (Jensen et al. 1996).

The results of this process are essential to validate the Watershed Assessment, to ensure that ecosystem relationships were considered adequately in Synthesis, and to show that management solutions have been implemented and are effective at achieving watershed objectives.

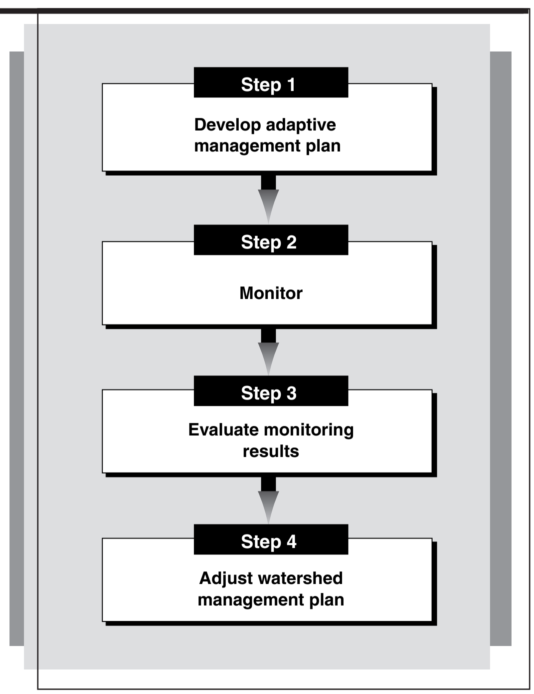
Adaptive Management Process

Step Chart

Procedure

The objectives of the Adaptive Management step are as follows:

- To create a system to monitor changes in the watershed.
- To evalute trends using monitoring data.
- To modify the watershed management plan as necessary.



Step 1. Develop adaptive management plan

The adaptive management plan will define the process for monitoring watershed conditions and, when necessary, modifying the watershed management plan (Box 1). The design of the adaptive management plan is best accomplished in cooperation with policy-level personnel with the authority to make a commitment of resources and technical personnel who can help identify scientific issues and evaluate monitoring data.

Box 1. Key elements of the adaptive management plan

- Monitoring objectives
- Information needs
- Available financial, technical, and human resources
- Process for evaluating monitoring results and changing watershed management plan
- Data management process
- Process for communicating results of watershed management actions

The adaptive management group should clearly define the objectives and timelines for watershed monitoring. Using information from the Watershed Assessment and Management Solutions processes, identify gaps in knowledge about watershed conditions and management activities. Prioritize the information needs so that resources can be allocated to the most important issues. Step 2 provides more detail on the type of monitoring to consider and resources for designing and implementing monitoring programs.

Box 2. Adaptive management in Oyster Creek, Texas

The Brazos River Authority in Texas is an example of how a long-term commitment to an adaptable watershed management process can achieve substantial progress. In the Oyster Creek watershed, data collected by volunteers suggested that industrial discharge was impacting water quality. After two years, industry came to better understand how they were affecting water quality. Similarly, the volunteers learned that other non-point source pollution would have to be addressed to solve the problems.

Industry re-engineered their discharge system to remedy the situation when they realized that the data were good and that other causes would be evaluated and addressed. As a result, the partnership has continued to grow, with industry supporting the volunteers with chemical supplies and monitoring kits. In addition, they are funding a constructed wetlands pilot project. A key to the success of this watershed management effort has been keeping the community aware of progress as it is made in the watershed and acknowledging the successes that occur.

Adapted from EPA (1997a)

Watershed management plans that rely on adaptive management require a long-term commitment of resources to ensure success (Box 2). Financial, technical, and other human resources need to be outlined, along with the specific responsibilities of each party.

The adaptive management group should also consider establishing criteria for modifying the watershed management plan based on monitoring results (Box 3). Separate criteria will be needed for each resource of concern, for example, water quality, water quantity, and aquatic life. Consideration should be

Box 3. Examples of criteria to evaluate the effectiveness of a watershed management plan

Watershed Issue	Criteria
Stream Temperature	• All streams shall meet state temperature standards in 10 years: Class A - 16°C Class B - 18°C Class C - 22°C • Complete review of stream classes to ensure consistency with beneficial use in 2 years
Fine Sediment	• 50% reduction in road sediment delivery to Bear Creek and Crazy Creek sub-basins in 5 years • 25% reduction in road sediment delivery to all other sub-basins in 5 years
Fish Passage	• 90% of dams and diversions will have fish passage structures in 5 years • 80% of irrigation diversions will have fish screens in 2 years, and 100% will in 5 years
Bull Trout	• Increase spawning population by 10% after 10 years

given to evaluating implementation and effectiveness at site-specific and watershed scales. Describing the expected detail and quality of monitoring data will allow the community to have confidence in the monitoring results and the need for changes in the watershed management plan.

Data management and the communication of results are also important considerations during the planning process. A great deal of data can be generated from a monitoring program. Managing these data so that they can be effectively analyzed and summarized is critical for maintaining interest and reporting progress on the watershed management plan.

It will be important to highlight trends and effectively communicate successes to the community. Consider how the group wants to promote the watershed management effort. The following strategies can help to educate and promote better watershed management:

- Demonstration sites.
- Watershed tours.
- Community workshops.
- Information campaigns.
- Brochures.
- Web site.
- Interpretive signs.
- Student projects.

Step 2. Monitor

Three types of monitoring may be needed to meet management objectives and to evaluate management practices:

1. **Implementation monitoring** (also called compliance monitoring) to determine whether standards and guidelines are being properly followed.
2. **Effectiveness monitoring** to determine whether the implementation of management solutions is achieving desired objectives.
3. **Validation monitoring** to determine whether the predicted results occurred and whether assumptions about the watershed and management system were correct (includes trend and baseline monitoring).

Further detail on designing and implementing monitoring programs can be found in the following documents:

- **General**
  - *Inventory and Monitoring Coordination: Guidelines for the Use of Aerial Photography in Monitoring* (Bureau of Land Management [BLM] 1991).
  - *Statistical Methods for Environmental Pollution Monitoring* (Gilbert 1987).

- **Forestry**
  - *Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska* (MacDonald et al. 1991).
  - *Evaluating the Effectiveness of Forestry Best Management Practices in Meeting Water Quality Goals or Standards* (EPA 1994).
  - *Techniques for Tracking, Evaluating and Reporting the Implementation of Nonpoint Source Control Measures: II. Forestry* (EPA 1997c).

- **Agriculture**
  - *Techniques for Tracking, Evaluating and Reporting the Implementation of Nonpoint Source Control Measures: I. Agriculture* (EPA 1997b).
  - *Monitoring and Evaluation of Agriculture and Rural Development Projects* (Casley and Lury 1982).

- **Urban**
  - *Techniques for Tracking, Evaluating and Reporting the Implementation of Nonpoint Source Control Measures: III. Urban Sources* (EPA 1997d)
  - *Environmental Indicators to Assess Stormwater Control Programs and Practices* (Clayton and Brown 1996).

Step 3. Evaluate monitoring results

It is beyond the scope of this guide to provide detailed information on statistical analyses, but other issues such as criteria for establishing trends and making changes in management should be established prior to the evaluation of results (Box 3). These standards and criteria may need to be modified based on resulting data.

Step 4. Adjust watershed management plan

A process for incorporating new information into the watershed management plan should be outlined in the adaptive management plan. Specific time frames for reevaluation and adjustment in the watershed management plan should be established. Reevaluation of the management plan will likely occur at 2-, 5-, or 10-year intervals to allow for implementation and monitoring of projects and programs. Standards for applying new information may need to be discussed by policy representatives.

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Technical Modules

Community Resources

Background and Objectives

It is the goal of this module to identify the natural resources valued by communities within a watershed in order to gain a better understanding of which resources will require protection.

> ***"For communities to grow, they must protect the underlying natural systems on which they are built."***
>
> EPA (1997a)

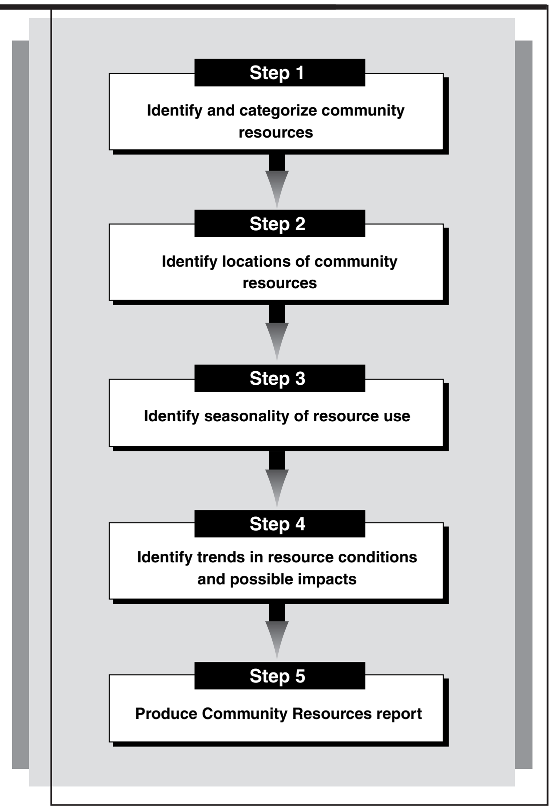
The Level 1 Community Resources assessment provides a structure for communities to identify and evaluate their valued natural resources in the watershed. The Level 2 assessment documents the importance of community resources, provides the rationale for protecting those resources, and supports the prioritization and implementation of management solutions.

Community Resources Module Reference Table

Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
CR1: What resources in the watershed are significant to the community?	• Anecdotal information • Community survey	• Collect and summarize existing information	• Detailed interviews • Work with historian or anthropologist • Community use analysis • Economic analysis
CR2: Where are community resources located?	• Anecdotal information • Watershed base map • Natural resource maps	• Collect and summarize existing information	• Detailed interviews • Field work
CR3: What is the seasonality of the community resource use?	• Anecdotal information	• Collect and summarize existing information	• Community use analysis • Work with historian or anthropologist
CR4: What processes or land use activities may be impacting community resources?	• Anecdotal information • Land use maps	• Collect and summarize existing information	• Detailed interviews • Field work
CR5: How have community resource conditions changed through time?	• Anecdotal information	• Collect and summarize existing information	• Detailed interviews • Field work • Community use analysis

Level 1 Assessment

Step Chart



Data Requirements

- Watershed base map
- USGS topographic maps
- Land use map

Products

- Form CR1. Categorization of community resources
- Form CR2. Trends in community resource conditions
- Map CR1. Community resources
- Community Resources report

Procedure

The primary objectives of the Community Resources assessment are as follows:

- To identify valued community resources.
- To identify locations of community resources.
- To evaluate changes in resource conditions through time.

Step 1. Identify and categorize community resources

Through interviews with community members, identify resources that have significance or value to the community. Many of the important community resources will have been identified during Scoping. Resources could include such things as wildlife, fish, drinking water, or a unique place that has a recreational or other unique value to the community. For example, many watersheds support fish populations that have long served to attract recreational fishermen or even commercial fisheries. Another example is a historical feature, such as a homestead from the early 1800s that documents history of pioneer life in the watershed. Lifelong residents may be especially helpful in identifying uses of natural resources in the watershed. Once a list of resources is generated, categorize them by resource use (Box 1) and record the information in Form CR1 (Figure 1).

Box 1. Community resource categories

- **Natural beauty:** resources that possess aesthetic value (e.g., a scenic lookout, a waterfall, or a wetland)
- **Recreation:** places and resources used for entertainment
- **Historical:** sites that possess historical significance
- **Subsistence:** resources used to provide food
- **Economic:** resources important for community employment and revenue
- **Education:** places or resources of educational value

EPA (1997b)

Figure 1. Sample Form CR1. Categorization of community resources

Resource	Site	Natural Beauty	Recreation	Historical	Subsistence	Economic	Education	Other
Rocky Ford	1	●	●					
Strawberries	2				●			
Catfish	3		●		●			
Off road vehicle trails	4		●					
Copper	5					●		
Beaver	6					●		
Elk	7		●		●			
Mushrooms	8		●		●	●		
Patton Homestead	9			●			●	
Gem Lake	10	●	●					

Step 2. Identify locations of community resources

Determining the location of community resources within the watershed is a critical step in evaluating possible land management impacts to these resources (Box 2). Exact locations of resources need not be identified if the goal is to preserve sensitive information; however, it is important that all resource locations be identified in some way. Identifying the presence of sensitive resources in a broad area or with coded symbols can maintain the security of important sites should the community wish to not widely advertise their existence or location.

Box 2. Sources of information on community resource locations

Local Town Hall, County Office, or Planning Board

- Local land use maps that show whether land is used for housing, commercial enterprises, agriculture, or open space
- Tax maps that show public or private ownership of land
- Flood insurance maps

State Environmental Agency

- Wetland delineation maps
- Watershed maps that show the waterbodies, wetlands, and other components of the watershed
- Land use maps
- Aerial photos
- Aquifer delineation maps

State Conservation or Land Acquisition Group

- Land use maps

State Wildlife and Fisheries Department or Department of Natural Resources

- Maps of state and local recreation areas
- Maps showing the distribution of different plants and animals throughout the state, including rare and endangered species, non-native species, and critical habitat

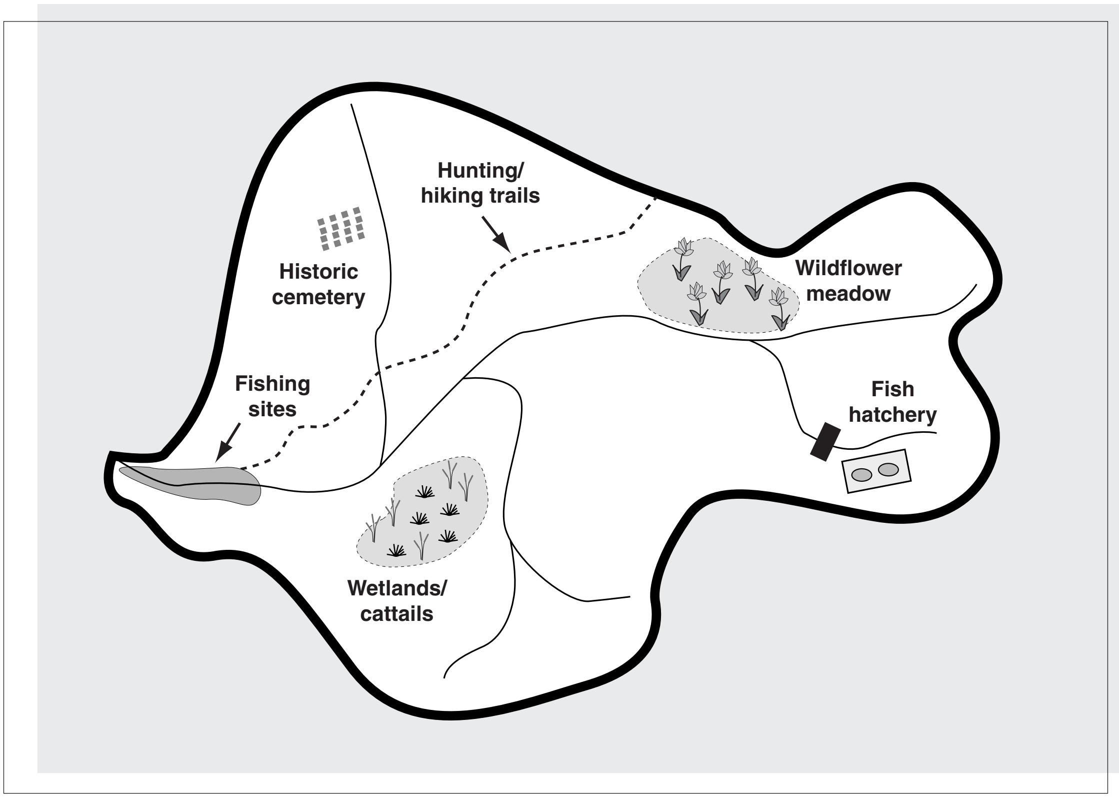
Federal Government

- Maps showing natural features of all parts of the United States (USGS)
- Maps of coastlines and ocean waters (The National Oceanic and Atmospheric Administration [NOAA])
- Maps of floodways and flood hazard areas (FEMA)

EPA (1997a)

To create Map CR1, add the locations of community resources to a base map of the watershed (Figure 2). Topographic maps that cover the watershed area can also be used. The community resources map can be a rough schematic or a more detailed map using GIS technology.

Figure 2. Sample Map CR1. Community resources



Step 3. Identify seasonality of resource use

Natural resources important to a community are often available only at specific times of the year (Box 3). For example, berries are gathered during the summer, and deer and elk are hunted during the fall. Understanding the seasonality of resource use provides a greater opportunity to connect land use impacts to community resource conditions.

Step 4. Identify trends in resource conditions and possible impacts

An important and easily available source of information on community resource condition trends is interviews with individuals who have lived in the community for many years. Information on conditions or trends, such as bad smelling drinking water or an obvious decrease in fish populations, can be obtained from long-term residents or from historical documents on community life. Another important source of information is state or federal restrictions on using community resources. Examples include restrictions on fish or water consumption, the federal listing of an endangered wildlife species, or the classification of a parcel of land as critical habitat.

Use the information collected to identify trends in resource conditions and summarize the trends in Form CR2 (Figure 3).

For each resource, also identify land use impacts on resource conditions. While many of the potential land use impacts will have been identified during the Scoping process, further investigation can help to refine the connection between land uses and resource conditions. The sources of resource impairment should also be recorded in Form CR2.

Box 3. Seasonality of resource use, an example from the Sol Duc watershed

Quileute Annual Cycle (approx. dates)	Sol Duc Watershed Activities
January	• Hunting small mammals: land otter and beaver • Steelhead fishing • Root digging: ferns
March	• Skunk cabbage
April	• Camas • Salmonberry and thimbleberry • Horsetail sprouts
May	• Bird hunting • Cedarbark • Spring (chinook) salmon • Blueback (sockeye) salmon
June	• Labrador tea and herbs

Shaffer et al. (1995)

Figure 3. Sample Form CR2. Trends in community resource conditions

Resource	Trend	Sources of Impairment	Related Modules
Native Vegetation	• Decrease in native plant species in local park	• Increased recreational use	• Vegetation
Wetlands	• Decrease in acreage • Loss of plant diversity	• Road construction • Agriculture • Peat harvesting	• Vegetation • Erosion
Trout	• Decreased populations • Loss of adequate habitat	• Urban development • Grazing contributing sediment to prime spawning habitat	• Channel • Vegetation • Hydrology • Water Quality • Aquatic Life

Step 5. Produce Community Resources report

The Community Resources report should summarize the location and use of important community resources and discuss possible impacts to and trends in resource conditions. Elements of this report include the following:

1. Description of Community Resources
   - Community cultural story (Box 4)
   - General location and use of community resources
   - Changes in resource use and conditions over time

2. Summary of Results
   - Conclusions
   - Map CR1. Community resources
   - Form CR1. Categorization of community resources
   - Form CR2. Trends in community resource conditions

3. Sources of Information
   - Methods
   - References
   - Assumptions
   - Confidence in the assessment
   - Further information needs

Box 4. Deer Creek cultural story

The Stillaguamish River watershed lies 40 miles north of the Seattle area in Washington State and is approximately 1,200 square miles. The Stillaguamish flows off the western foothills of the Cascade Mountains down to Puget Sound. The river and its tributaries support four salmon species, steelhead trout (sea-run rainbow trout), sea-run and resident cutthroat trout, and many other species of fish. These fish were once plentiful but have suffered from degradation of their habitat and over-harvest during the past century. The estuary of the Stillaguamish also supported abundant fish and shellfish populations.

The watershed is the historic home of the Stillaguamish Tribe of Native Americans. The tribe depended on the abundant fish resources in the watershed for their food and for trade. Salmon were harvested almost year round and were eaten fresh, cooked over alder campfires, and dried. Their roe (eggs) were considered a delicacy and a good source of oil and protein. The Stillaguamish culture honored the salmon and steelhead, which provided a central focus for their myths, legends, and religion.

Europeans began to settle the area in the late 1800s; however, they tended to settle in the lowlands near Puget Sound. They also found food, sustenance, and sport in the salmon and steelhead of the watersheds.

In 1911, a world famous author and sportsman, Zane Grey, journeyed to the Pacific Northwest to fish for steelhead in a famous tributary stream of the Stillaguamish River, Deer Creek. He later wrote of traveling all day by train into the forests north of Seattle until he finally reached the town of Oso at the mouth of Deer Creek. He then climbed aboard a logging train and headed into the Deer Creek watershed. Arriving finally, and climbing over moss covered downed trees, he described Deer Creek as the most crystal clear, emerald green trout stream he had ever seen.

Today, Deer Creek runs chocolate brown year round. Steelhead fishing has been closed for decades, and the Deer Creek steelhead are perhaps extinct. The salmon and steelhead runs of the Stillaguamish River are now some of the weakest in the region, and most years no fishing by sportsmen or tribal fishermen is permitted.

Level 2 Assessment

The purpose of the Level 2 Community Resources assessment is to collect additional information on the importance of the resources identified in the Level 1 assessment. Resources in the watershed might have social, cultural, or recreational significance, or they might support the economy or quality of life in the community. Documenting the importance of community resources will provide the rationale for protecting those resources and will support prioritization and implementation of management solutions. A useful source of information on evaluating the benefits provided by community resources is *Community-Based Environmental Protection: A Resource Book for Protecting Ecosystems and Communities* (EPA 1997a).

Social and Cultural Importance of Community Resources

Describing the social and cultural significance of watershed resources will help the community to better document their cultural heritage, understand their relationship to the natural environment, and communicate with others about preserving valued resources. The following methods can be used to collect information on the cultural significance of community resources:

- Perform personal interviews with natives, long-term residents, and other community members.

- Perform fieldwork to locate community resources.

- Work with a historian, anthropologist, or archaeologist familiar with the region.

Topics that could be addressed include the following:

- Describe traditional uses of resources, such as plants, fish, and wildlife for food or waterways for transportation. In addition to existing resources, consider resources that have been degraded or lost.

- Provide additional detail on the cultural or historical significance of locations in the watershed.

Economic Importance of Community Resources

Another way to establish the importance of community resources is to identify, and if possible to quantify, their contribution to the local economy. The economic value of community resources is most obvious when the community's economy is based on agriculture or on the extraction of natural resources, such as fish, shellfish, trees, coal, and oil. Other ways that natural resources can contribute to a community's economy include the following:

- Natural areas can be important for recreation-based businesses that attract tourists, anglers, hunters, birdwatchers, and hikers.

- Lakes, parks, and preserves can enhance property values.

- Wetlands, forested areas, and floodplains can provide natural flood water storage and water filtration, reducing the need for capital projects to replace these functions, such as levees and seawalls or water treatment plants.

Table 1 lists possible indicators and sources of information for documenting the economic value of community resources.

Importance of Community Resources for Quality of Life

Natural resources can also contribute to a community's quality of life, although this type of resource value is more difficult to quantify than economic value. Examples of benefits that can be provided by natural resources include the following:

- Natural beauty.
- Human health and safety.
- Recreation.
- Sense of community.
- Educational value.

Table 2 lists possible sources of information for documenting the importance of community resources for quality of life.

Table 1. Information sources for assessing the linkages between natural resources and the local economy

Overall Assessment Objective	Sample Indicators	Possible Sources of Information
Assess dependence of local tax revenues on ecosystems	• Annual revenue from fees for use of parks and beaches	• Local parks and recreation department, local revenue department
Assess dependence of local economy on nature-based recreation	• Annual revenues from and/or employment in local outdoor recreational businesses (e.g., boat rentals, nature tour guides, birdwatching, and cross-country skiing centers) • Annual number of fishing or hunting licenses issued in the county • Annual number of "activity days" for various categories of outdoor recreation (e.g., fishing, hunting)	• Local merchants • Local chamber of commerce • State fish and wildlife department • State Comprehensive Outdoor Recreation Plans (contact state tourism and recreation agency) • U.S. Fish and Wildlife Service (USFWS), *National Survey of Fishing, Hunting, and Wildlife Associated Recreation*, published every six years • Local chamber of commerce
Assess need for clean water for industrial use	• Use of water by food processors, breweries, etc.	• Local water authority • Local chamber of commerce • Local business leaders or representatives of relevant companies
Assess impact of ecosystem health on residential property values	• Relative cost of otherwise similar houses located near and several blocks away from a local park • Qualitative indicator based on home buyer and realtor opinions on premium paid for properties located near environmental amenities (e.g., clean rivers, parks)	• Local registry of deeds • Survey of recent home buyers in the area • Local realtors
Assess trends in commercial and residential development	• Urban Sprawl Index: rate of conversion of open land to suburban/urban development • Percentage of building permits in downtown/urban core vs. non-urban or suburban areas	• Municipal/county/state land use planning offices • Local building and permits office
Assess local dependence on "extractive" natural resource-based activities	• Revenues of local forest products industry relative to revenue in all industries • Employment in local forest products industry relative to employment in all industries	• U.S. Department of Commerce, Bureau of the Census, *County Business Patterns*, phone: (301) 457-4100 • U.S. Department of Commerce, Bureau of Economic Analysis, *Regional Economic Information System*, phone: (202) 606-9900 • USFS, *Forest Statistics*, by state
	• Revenues of local commercial fishery relative to revenue in all industries • Employment in local commercial fishery relative to employment in all industries	• U.S. Department of Commerce, Bureau of the Census, *County Business Patterns*, phone: (301) 457-4100 • U.S. Department of Commerce, Bureau of Economic Analysis, *Regional Economic Information System*, phone: (202) 606-9900 • National Marine Fisheries Service (NMFS) in the U.S. Department of Commerce maintains county-level data on landings and value of catch • Local chamber of commerce
Assess sustainability of local resource-based industries	• Ratio of the amount, health, and diversity of timber regrowth to timber cut • Stability in numbers of juvenile and young-of-year in fish population over time	• USFS, *Forest Statistics*, by state • NMFS data (see above)

EPA (1997a)

Table 2. Information sources for assessing the linkages between natural resources and local quality of life

Overall Assessment Objective	Sample Indicators	Possible Sources of Information
Characterize importance of ecosystem to local education	• Number of school field trips to natural areas • Number of visitors to local arboretum, bird sanctuary, or state and national parks	• Local schoolteachers • Management office of relevant organization (e.g., arboretum)
Assess flood control services provided by local wetlands	• Qualitative indicator based on flooding history of area with wetlands and similar areas where wetlands have been lost to development	• Newspaper archives • Local land use officials • Local emergency management officials
Characterize dependence of town on local surface and groundwater	• Percentage of household water supply from local sources	• Local public works department • Regional water supply authority
Assess availability of land for recreation	• Acres of land/open space available for recreation per 1,000 people in the community	• Local land use officials • Local or state parks and recreation officials
Characterize level of recreational activity dependent upon ecosystems	• Annual number of "activity days" for various categories of outdoor recreation (e.g., rafting and kayaking, fishing, hunting, and visitor days to local resorts and campgrounds) • Trends in beach closures or fishing advisories • Fate and effects of sanitary waste and refuse on ecosystems	• USFWS, *National Survey of Fishing, Hunting, and Wildlife Associated Recreation*, published every six years • State Comprehensive Outdoor Recreation Plans, contact state tourism and recreation agency • County or municipal records for sanitary treatment and waste removal from recreation site

EPA (1997a)

References

Shaffer, J. A., B. Warner, and J. Powell. 1995. Sol Duc Pilot watershed analysis: Cultural module. Olympic National Forest, Olympia, Washington.

U.S. Environmental Protection Agency (EPA). 1997a. Community-based environmental protection: A resource book for protecting ecosystems and communities. EPA 230-B-96-003, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1997b. Cultural ecosystem stories: A guide to preparing natural resource case studies (DRAFT). EPA, American Indian Office, Washington, D.C.

Form CR1. Categorization of community resources

Resource	Site*	Natural Beauty	Recreation	Historical	Subsistence	Economic	Education	Other

** Identify locations on Map CR1. Community resources*

Form CR2. Trends in community resource conditions

Resource	Trend	Sources of Impairment	Related Modules

Aquatic Life

Background and Objectives

Streams, lakes, and wetlands provide habitat for cold and warm water fish, amphibians, and the species on which they depend. The Aquatic Life module provides a procedure for evaluating the needs of valued aquatic species and the condition of stream, lake, and wetland habitats. In this module, the term valued aquatic species refers to a single species, several species, or a functional group or guild of species that were identified for assessment during Scoping. The assessment is designed to determine how the flows of water, heat, pollutants, and other stream inputs are affecting the habitat and other needs of valued species.

For a Level 1 assessment the analyst collects and summarizes existing information on the population status, distribution, and ecological needs of the species. This information is then used to develop working hypotheses regarding how the species and habitat in the watershed have been impacted. Using existing habitat data, habitat in the watershed is evaluated based on the species' ecological needs. The results of the habitat evaluation are used to support or disprove the working hypotheses or to identify the need for further data collection and assessment.

The module also provides information on methodologies that can be used for a Level 2 assessment. While Level 1 assessment relies primarily on existing information, Level 2 assessment is used when more extensive data collection and analyses are needed.

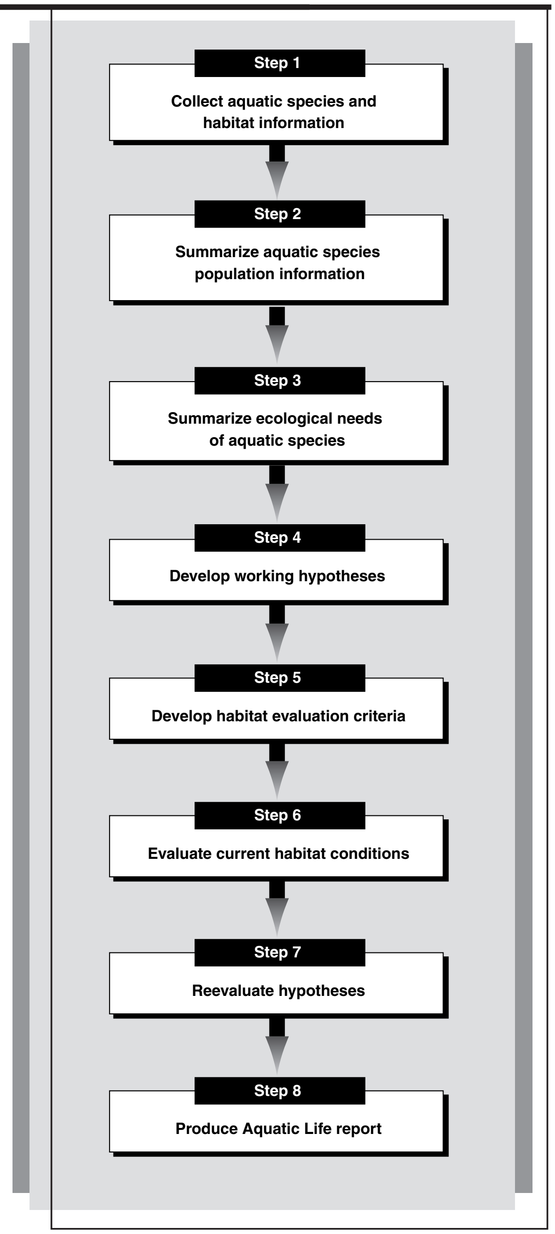
Aquatic Life Module Reference Table

Critical Questions	Information Requirements	Level 1 Methods/Tools*	Level 2 Methods/Tools*
AL1: What are the valued aquatic species that are present in the watershed?	• Information on species and distribution	• Consult watershed and species experts • Evaluate existing information • Investigate watershed history	
AL2: What are the distribution, relative abundance, population status, and population trends of the aquatic species?	• Historical and current population estimates and species distribution information	• Consult management agencies, watershed experts, and species experts • Collect existing regional information	• Collect watershed-specific information • Population modeling • Bioassessment methods
AL3: What are the requirements of various life history stages of the aquatic species?	• Scientific literature • Regional information and regional models	• Identify the habitat requirements (by life stage, season, etc.) • Consult with species experts	• Instream Flow Incremental Methodology or habitat suitability indices analysis • Suitability criteria development • Regional models
AL4: What are the habitat conditions for the aquatic species?	• Scientific literature • Existing habitat survey information	• Develop descriptions of current habitat conditions • Develop and apply evaluation criteria	• Collect watershed-specific information • Modeling
AL5: What connections can be made between past and present human activities and current habitat conditions?	• Historical information on watershed conditions • Current information on watershed conditions • Aerial photos	• Summarize watershed history • Consult watershed experts • Analyze aerial photos • Evaluate existing habitat survey information	• Modeling • Expert system

* Overlap exists between Level 1 and Level 2 methods. Often, the difference consists of the level of effort expected or whether existing information is used or the collection of new information is needed. Most Level 2 methods incorporate actions that are identified here as Level 1 methods (for example, consulting watershed or species experts).

Level 1 Assessment

Step Chart



Data Requirements

- Map of streams, lakes, and wetlands within the watershed.
- Land use map or recent aerial photos.
- Information on the population status, population trends, and distribution of the aquatic species. Sources for this information include agency records, species distribution maps, basin management plans, stock management plans, historical and current population assessments, and endangered species assessments and descriptions.
- Information on aquatic habitat conditions from state and federal agency records and existing habitat surveys.
- Information on dams, diversions, stream channelization, and alteration of lakes or wetlands. Much of this information may be historical.
- Information on existing or proposed listings under the ESA or under state endangered species laws.
- Professional opinions and information from resource professionals with expertise in the region, the watershed, or the aquatic species.
- Scientific literature on species' ecological needs.

Products

- Form AL1. Summary of hypotheses
- Map AL1. Aquatic species distribution
- Map AL2. Aquatic habitat distribution
- Map AL3. Aquatic habitat conditions
- Aquatic Life report

Procedure

Step 1. Collect aquatic species and habitat information

Collect available historical and current information on the valued species from federal, tribal, state, and local agencies and other community members. The information requirements are summarized in the Data Requirements section, above. Tracking down available information can be a time-consuming part of the process. Information gathering should also include interviews with agency biologists and any other individuals with expertise in either the assessment area or the aquatic species.

Step 2. Summarize aquatic species population information

Summarize the information from Step 1 focusing on the population status of the aquatic species and its distribution. Also summarize any available information about trends in population or distribution. The amount of detail for each of these topics may vary. Population information may be available only for an area larger than the watershed in question (e.g., a river basin or multi-state area) or may be very detailed (e.g., years of creel census information for a particular lake). Information may also be anecdotal (e.g., great declines in the range of a given species over the last 150 years). It may be that consulting watershed experts will yield the best information available.

At this point it may be useful to create Map AL1, the distribution map for the aquatic species under study. It may also assist other analysts to have this map.

Step 3. Summarize ecological needs of aquatic species

Using information that was gathered in Step 1, summarize descriptively or in a table the important life history patterns of the aquatic species and the species' ecological needs during each life stage (Box 1). This information, together with the distribution information, will help in determining the areas of the watershed that are important for different life history requirements or times of year. The information on life history requirements will also contribute to the development of hypotheses and habitat evaluation criteria. Examples of life stages include spawning, incubation, rearing, adult, and in- and out-migration. Requirements should be represented by factors that are measurable (e.g., water temperature) rather than those that, while important, are less likely to be measurable (e.g., genetic diversity).

Box 1. Life history preferences for stream-resident brook trout (*Salvelinus fontinalis*)

Life stage	Habitat preferences	Timing
Spawning	0.1 - 3" gravel, redd sizes < 2 ft^2	September - November
Incubation	No flood flows (causes redd scouring) or fine sediment inputs (smothers eggs)	Winter
Winter habitat	Pools with cover, interstitial spaces in cobble/gravel substrates	Water temperatures < 4°C
Summer habitat	Water temperatures 10°C - 19°C, adequate food (primarily insects, some fish), escape cover	Water temperatures > 4°C

Meehan (1991), Stoltz and Schnell (1991)

Step 4. Develop working hypotheses

Summarize important historical events and specific situations of concern

Using historical information and management plans, summarize past events and current situations in the watershed that are likely to have had an impact on either the population of the aquatic species or on habitat conditions. Summaries can be in text or table format. Following are examples of events or situations that could affect species or habitats:

- Historical presence or absence of a species (such as beaver) in a watershed.
- Historical introduction of an exotic species and subsequent interactions between native and introduced species.
- Past management actions such as hatchery operations or stocking programs.
- Disturbance events such as land clearing, dam construction, alteration of lakes or wetlands, floods, or fires that may have contributed to current habitat conditions.

Also consider situations such as changes in inputs of heat (e.g., loss of stream shading), sediment (e.g., landslides), streamflow (e.g., dams or diversions), and riparian conditions (e.g., grazing, land clearing). Consultation with other analysts at this stage may be very useful.

Channel
Hydrology
Vegetation
Water Quality
Historical Conditions

Develop working hypotheses about impacts on aquatic species and habitats
Using the information collected and summarized in the previous steps, develop working hypotheses about cause-and-effect relationships between historical actions or current situations, a change in inputs to the aquatic system, and potential impacts on the aquatic species or its habitat.

Channel
Vegetation
Water Quality

It is not expected that enough information will be available to allow statistical testing of hypotheses in the scientific sense. Rather, the process of developing hypotheses is used to focus the assessment process and facilitate discussions. Communication among the Aquatic Life, Channel, Vegetation, and Water Quality analysts is essential to incorporate findings collected for one module into the assessment of another (e.g., water quality information as a habitat parameter), to identify data gaps, and to refine hypotheses.

A suggested format for summarizing working hypotheses is provided as Form AL1. Examples of general hypotheses are provided in Figure 1; the analyst should be able to generate more specific hypotheses than those shown.

Step 5. Develop habitat evaluation criteria

Generate a table of proposed habitat evaluation criteria based on the life history requirements of the aquatic species. Because of the importance of conclusions that will be developed using the criteria, community members and watershed experts should participate in criteria development whenever possible. This will provide a chance for feedback on variables used and the critical values selected.

Habitat evaluation criteria are defined in this module as characteristics of the environment in which an organism lives that can serve as effective indices of habitat condition and indicators of human-caused change. Criteria should be quantitative if possible. General categories of habitat criteria include the following:

- Floodplain characteristics.
- Riparian characteristics.
- Streambank characteristics.
- Stream channel, lake, and wetland characteristics.
- Streambed substrates.
- In-stream wood debris.
- Habitat quantity.
- Water quantity and quality.

Figure 1. Sample Form AL1. Summary of hypotheses

Species	Sub-basin	Description	Hypothesis	Source (include watershed expert as appropriate)
Stream-dwelling fish or amphibians	Beaver River	Beavers were common in the watershed prior to settlement and are uncommon now.	Pool, backwater, and wetland habitats formerly created and maintained by beavers may be less common now than they were in the past. This may have had the following impacts on the aquatic species…(*depending on the species preference for or dependence on these habitats*)	Historical records
Stream-dwelling fish or amphibians	Trout Creek	A severe fire burned the sub-basin in 1977.	Sediment or wood debris may have entered the stream channel, increasing sediment load and changing channel conditions. This may have had the following impacts on the aquatic species…(*depending on the species preference for or dependence on the channel conditions that result from these inputs*)	Agency records
Stream-dwelling fish or amphibians	Prairie Creek	Riparian trees were removed along the mainstem (1960-1975); current riparian vegetation is pasture grasses.	Changes in the riparian vegetation may have caused water temperature changes, changes in in-stream habitat conditions, or stream channel shifts. This may have had the following impacts on the aquatic species…(*depending on the species water temperature preferences or tolerances and habitat requirements*)	Aerial photos
A native trout	Deer Creek	Stocking of brook trout was widespread in the late 19th and early 20th centuries. Brook trout are established and will displace native trout.	The distribution of native trout may cover a smaller area now. This may have had the following impacts on the aquatic species… *(impacts could include population numbers, breeding opportunities, higher fishing pressure, etc.)*	Historical records
Brook trout	Spring Creek	Past management has relied on hatchery stocking. Current goals protect naturally spawning populations.	Because the management goal now supports natural spawning, the condition of the spawning areas may be critical for maintaining population numbers. Stream survey information indicates the following about conditions of spawning habitat…This may have had the following impacts on the aquatic species…(*depending on the species preference for or dependence on these conditions*)	Basin management plan

Identify regional criteria or develop literature-based criteria

For some species, appropriate habitat criteria and associated survey methods may already have been developed by management agencies. If regionally appropriate habitat evaluation criteria cannot be located for the aquatic species, criteria should be developed based on scientific literature and consultation with regional managers and biologists (Box 2). Interviews with watershed or species experts will provide valuable information.

Box 2. Guidance for developing habitat evaluation criteria

Bovee (1986) presents an excellent discussion of methods to develop habitat suitability criteria using watershed experts' opinions and scientific literature for situations in which collection of additional field data is not possible.

Box 3. Sources of habitat suitability models

Information on habitat suitability models can be obtained from regional offices of the USGS Biological Resources Division, particularly the Midcontinent Ecological Science Center, Fort Collins, Colorado (**www.mesc.usgs.gov**). The regional office in Lafayette, Louisiana (National Wetlands Research Center) may also have some documents available online (**www.nwrc.gov**).

Habitat criteria have been summarized for many species by the USFWS and the USGS Biological Resources Division based on investigations presented in the scientific literature (Box 3). These documents can suggest both appropriate criteria for consideration and a starting point for determining regionally appropriate values and ratings in discussion with watershed experts.

The example provided in Box 4 illustrates how habitat evaluation criteria can be developed based on scientific literature. Both critical thinking and common sense will be

Box 4. Development of habitat evaluation criteria based on scientific literature

Stuber et al. (1982) provide the following information on habitat conditions for largemouth bass (*Micropterus salmoides*) in rivers.

Life stage	Parameter	Good habitat conditions	Moderate habitat conditions*	Poor habitat conditions
Adult, juvenile, fry	Dissolved oxygen	> 8 mg/L	4 - 8 mg/L	< 4 mg/L
Adult, juvenile	Turbidity (suspended solids)	< 25 ppm	25 - 100 ppm	> 100 ppm
Adult, juvenile	Percentage pool habitat	> 60%		< 20%
Adult, juvenile	Percentage cover in pools	40 - 60%		
Adult, juvenile	Summer water temperature	24 - 30°C		< 15°C and > 36°C
Incubation	Water temperature	13 - 26°C		< 10°C and > 30°C
Fry	Water temperature	27 - 30°C		< 15°C and > 32°C
All	Salinity	< 1.66 ppt		> 4 ppt

* Moderate values are listed here if provided by Stuber et al. (1982).

Using the habitat conditions table for largemouth bass, habitat evaluation criteria could be developed for discussion with watershed experts. For example, dissolved oxygen criteria could be developed fairly simply. Levels greater than 8 mg/L could be rated “good,” levels between 4 and 8 mg/L “moderate,” and levels less than 4 mg/L “poor.” For two other parameters, percentage pool habitat and summer water temperature, the “good” and “poor” ranges could be easily defined, but the question of how to assign a “moderate” rating might require more discussion. A “moderate” rating for percentage pool habitat could be assigned to the 30 - 50% range, and a “moderate” rating for summer water temperatures could be assigned to the 15.5 - 23.5°C range (assuming typical summer water temperatures are not less than 15°C).

necessary during this process. The goal is to identify a small number of appropriate criteria for each life stage of the aquatic species. Too many criteria can confuse the assessment. Focus should remain on those criteria that watershed experts agree are important to specific life stages and for which information has been collected. Criteria should also be measurable to allow comparison among sub-basins (e.g., stream shading and average tree height would be more useful than would a general description of riparian function). The criteria should help to illustrate where land use and human interaction with the landscape have the potential to change habitat conditions or alter population status.

Box 5. Development of human disturbance criteria

> In a watershed with a mix of agricultural, urban, and suburban land uses, the identified issues are delivery of sediment and increased runoff to the stream during winter storms and fragmentation of the riparian corridor by roads, pipelines, and powerlines. Aerial photos can be used to make a count of road stream crossings per mile, which will indicate the number of delivery points for sediment and runoff and the relative amount of disturbance in the riparian corridor. Specific criteria for evaluating the level of human disturbance can be developed by comparing the number of road stream crossings per mile with regional values or by making comparisons across sub-basins or land use categories
>
> *May et al. (1997)*

Develop human disturbance criteria

In addition to the evaluation criteria for specific habitat conditions, it might be appropriate to use an index of human disturbance, such as road density or percentage impervious surface (Box 5).

Step 6. Evaluate current habitat conditions

Use the information collected in Step 1 and the criteria developed in Step 5 to evaluate the current habitat conditions in the watershed. For each stream reach, lake, wetland, or sub-basin for which information is available, habitat is evaluated for the species or life stage that occurs there. The evaluation can also group species as appropriate or analyze groups of stream reaches, lakes, or wetlands where a particular species or life stage is important (e.g., spawning areas). In addition, the question of access into and out of particular habitats should be evaluated as necessary (considering both in- and out-migration, as appropriate). The analyst should focus both on typical habitats and habitats of special concern. Describing overall conditions is as important as, or more important than, describing unique or uncommon situations.

Compile a summary of available data on habitat conditions and apply the habitat evaluation criteria. An example of a format that could be used to summarize data is provided in Figure 2.

Figure 2. Sample habitat data summary form

Reach ID	Distance sampled	Pool Characteristics				Substrate Characteristics			
		Percent pool habitat	Rating	Percent cover in pools	Rating	Dominant substrate	Rating for spawning/ adult habitat	Sub-dominant substrate	Rating for spawning/ adult habitat

Water Quality Sample ID	Reach ID where sample was taken	Water Quality Characteristics				Water Temperature Characteristics			
		Dissolved oxygen (mg/L), Rating	Turbidity (NTU), Rating	Salinity (ppt), Rating	Additional parameter, Rating	Summer water temperatures (°C) (mean, range)	Rating	Incubation period water temperatures (°C)(mean, range)	Rating

Several criteria for a particular stream reach might fall into the "moderate" category. While it may be fairly straightforward to look at the criteria in the "poor" category and hypothesize connections between human-caused inputs and stream processes, the meaning of the "moderate" ratings can be less clear. Values that fall into a moderate range may indicate that conditions are changing from poor to good or from good to poor. The analyst can look for supporting evidence from other parameters in similar categories, such as other indicators of riparian condition or of in-stream habitat quality.

There may be situations in which only general information, not specific data, is available for a parameter considered important by the analyst or the watershed experts. In that situation, professional judgments can be made and indicated as such in the report. In addition, data gaps that were identified should be noted.

Habitat information should be evaluated critically. Habitat surveys are a snapshot of dynamic aquatic and riparian systems. Data may have been inconsistently collected, and sampling protocols will tend to change over time. Also, data may not be summarized in a manner helpful to the analyst. For example, data collected between two access points may cover several channel types. Events occurring after a survey (e.g., a flood) may have left the habitat in a different condition than data indicate. Collaboration between analysts will be the best source of information to assess these situations.

Channel
Hydrology
Vegetation
Water Quality

Step 7. Reevaluate hypotheses

Using the results of the habitat evaluation, reevaluate the working hypotheses developed in Step 4 (Box 6). Determine whether the information collected on current habitat conditions supports the hypotheses or indicates that the hypotheses should be revised. Also identify any hypotheses for which further data collection or input from other analysts will be needed. The hypotheses will be discussed with the other analysts during Synthesis.

Box 6. Sample reevaluations of hypotheses using conclusions from habitat evaluation

Hypothetical example 1

Shading levels are good in three of five sub-basins in the Little Pine watershed. The hypothesis is that, for the other two sub-basins, summer water temperatures may be less than optimal and may be limiting fish population numbers. Comparing available water temperature data and habitat criteria, it appears that summer water temperatures are higher than preferable but not lethal in the two sub-basins. No fish population or distribution data were available. Given that the hypothesis cannot be proved or disproved with existing information, the analyst then states the suspected problem: Shading levels are less than optimal in the two sub-basins, with possible negative impacts to fish habitat or populations from high water temperatures. This would then generate the following question for other analysts during Synthesis: Are stream shading levels in the two sub-basins likely to be increasing, decreasing, or staying the same? What effects might this have on future water temperatures?

Hypothetical example 2

Bullfrogs, an introduced non-native species in the western United States, are now present throughout the Bull Run watershed. Because it is well known that bullfrogs are very successful predators on native frogs, the following hypothesis was developed: Native frogs are now rarer than in the past and may only exist above barriers to bullfrogs. Native frog distribution information for the watershed shows that native frogs are in fact rare, except in one stream system where bullfrogs have been excluded. The analyst then revises the hypothesis by adding the idea that the small stream system should be identified as refugia for the native frogs.

Step 8. Produce Aquatic Life report

Produce maps

At least two and possibly three maps will be generated from the assessment. Map AL1 will present species distribution. An option is to also present historical distribution if it will contribute to the Synthesis discussions.

Maps AL2 and AL3 will present habitat distribution and a summary of habitat conditions. The habitat distribution and condition information could also be combined on one map, depending on the amount of information to be presented. The information included on the maps will vary with the aquatic species, its specific habitat requirements, and the geomorphology of the watershed. Examples of information that could be presented include the following:

- Spawning habitat, rearing habitat, adult habitat, and juvenile habitat (there may be "important/primary" and "less important/secondary" categories).
- Critical habitat (e.g., location of refugia or the only occurrence of a habitat type in the watershed).
- "Important/primary" habitat that is in degraded condition or in very good condition.
- Areas where habitat is in "naturally poor" condition (e.g., due to geology or soils).
- Areas where in- or out-migration is blocked.
- Dams, diversions, or irrigation withdrawals.
- Other topics of concern identified by the analyst (e.g., water quality problems).

Not all topics on this list will necessarily be presented on all maps. Whether one or two maps are needed to present the summary of habitat condition will depend on the number of aquatic species and the complexity of the situation. Often cartographic requirements that limit the amount of information easily included on a single map will prevail. Maps can be separated by concerns for a particular species, concerns during a specific time of year (such as winter, summer, or spawning periods), or other appropriate concerns. It may be helpful to present the channel segmentation and classification on one of these maps to assist in the development of hypotheses regarding channel and habitat responses to inputs such as sediment, water, and vegetation.

◀ Channel

Produce report

Produce a report summarizing information gathered and evaluation results. Critical questions should be kept in mind while developing the report. The report should include the following elements:

- A description of the valued aquatic species, their population statuses and trends, and their current distribution.
- A table summarizing life history requirements, which will be helpful for other analysts during Synthesis.
- A description of the historical abundance of and use of the watershed by the aquatic species.
- A description of the habitat evaluation criteria and the sources and methods used to develop the criteria.
- A summary of current habitat conditions within the watershed. Descriptions can be separated based on channel type, species or life stage, or sub-basin.
- A discussion of the hypotheses developed and evaluated.
- Identification of data gaps.
- A summary of the level of confidence in the assessment and in the various conclusions that have been reached (Box 7).

The report could also identify areas that may be critical habitat for a particular life stage, reaches with water quality concerns, reaches of high-quality habitat or of degraded habitat, and obstructions and blockages to migratory species or life stages. Comparisons could also be made between current conditions and descriptions of reference conditions for the particular ecoregion, if they are available.

Box 7. Sample summaries of confidence in the assessment

Confidence is high in amphibian distribution information in the wetlands of the Bog Creek sub-basin because of recent extensive baseline surveys.

Confidence is low to moderate for assessment of habitat conditions for brook trout in the Big Pine Creek sub-basin. No habitat surveys have been performed, and the assessment was made using aerial photos.

Confidence is low regarding issues about water temperature for small lakes in the Ruby Valley watershed. No water temperature data were available, although watershed experts expressed concern about the potential for high summer water temperatures.

Level 2 Assessment

This section presents a selection of Level 2 assessment tools for aquatic species and aquatic habitat. Some methods allow the analyst to study the species of concern (or group of species) directly by assessing population size or species associations. Others use a measure of habitat availability or quality to assess ecosystem health or impacts from land use. Other methods incorporate approaches from population modeling and ecosystem theory.

This list of methods is not exhaustive. The analyst will need to consult with experts to determine whether a particular method is appropriate for the area under analysis and the topic of investigation.

Some of the methods presented below are fairly simple, while others require more time and resources. The analyst should consider whether extensive analysis is warranted by the magnitude of the problem under study and is feasible with the resources and information available. It is possible that a simpler approach will generate results with sufficient confidence to develop conclusions and policy recommendations. It should also be recognized that the science of ecosystem analysis is evolving, and tools and methods are continually under development.

Use of Aquatic Habitat Models

Instream Flow Incremental Methodology (IFIM)

The IFIM was developed by the USFWS to allow predictions of habitat quantity and quality for various aquatic species in riverine environments (Bovee 1982). It was developed for use in water allocation negotiations and operation of controlled rivers. Modeling is based on a combination of hydraulic factors measured in the river and general habitat preferences of fish species and life stages.

The strength of this approach is that it allows a quantitative estimate of gains and losses in fish habitat as flows incrementally change. One difficulty is that it can be expensive to collect the physical measurements and fish observations needed to generate a good quality model.

Habitat Suitability Indices (HSI)

The USFWS has also developed a series of descriptive models called HSIs for many species, including many fish and other aquatic-dependent species. The HSIs are developed from research literature and expert reviews and are intended to aid in identifying important habitat variables. They are hypotheses of species-habitat relationships, and users are expected to recognize that the veracity of model predictions will vary between places and will depend on the extent of the database for individual variables (Stuber et al. 1982; Terrell et al. 1982). This assessment tool can also be used in a Level 1 assessment.

The strength of these models is that they provide a quantitative index of habitat quality. They also present good summaries of what is known about the habitat requirements and preferences of a particular species. The analyst can then compare this information with the specific situation under analysis, choose the factors that are important, and devise the appropriate analysis approach. HSIs are different from the "expert system" approach outlined below because they require a higher level of expertise.

Use of an Expert System

Expert systems are designed to allow a less-experienced analyst access to the thinking and experience of those with greater expertise on the topic under consideration. They can be a series of questions posed to a group of experts, a dichotomous key, or a computer program. The strength of this approach is that the experience of experts can be accessed in a structured format. One problem with this approach is that it lends itself to a "cookbook" analysis, which might neglect an important habitat situation that was not addressed.

An example of an expert system is presented in MacDonald et al. (1991). They present an expert system that, through a series of questions, allows the investigator to generate a list of physical and biological parameters to be used in the design of water quality monitoring to investigate impacts from land use practices. An example of a dichotomous key for determining limiting factors for coho salmon freshwater life stages is presented by Reeves et al. (1989). This approach relies on field data for habitat parameters as well as estimates of adult escapement needs (see limiting factors discussion in the "Use of an Ecosystem Approach" section, below).

Use of Bioassessment Methods

Bioassessment methods vary widely, although all generally use measures of population size or makeup (e.g., number of species) to assess ecosystem health and response to land use activities. Examples include a simple presence/absence study for a single species and investigations of predator-prey relationships or other trophic-level interactions (Hauer and Lambert 1996). Multi-species sampling for fish and macroinvertebrates is also used to develop comparisons of population or habitat conditions within regions (Plafkin et al. 1989, Karr 1991).

Strengths of this approach include the fact that the aquatic species itself—rather than an indicator such as habitat conditions or water quality—is under study. Also, regional values for fish and macroinvertebrate species assemblages have been generated for many states or ecoregions (e.g., Kerans and Karr 1994). Difficulties with this approach include potentially high costs in time and resources and difficulty in finding reference sites to define good habitat conditions with which to compare the area under study.

Use of Population Model Predictions

The topic of population modeling is too large to address in this module; however, existing information on population status and trends for the aquatic species of concern will always be useful to the analyst. In addition, incorporation of population model predictions may also be considered by the analyst. The analyst should be informed about model strengths and weaknesses as well as the limits of both the data used in model development and the range of model predictions.

Use of an Ecosystem Approach

Watershed analysis is itself an approach that takes an integrated view of ecosystem processes and biological responses. Scientists have developed other methods or approaches that incorporate aspects of watershed analysis, such as assessment of watershed processes, with approaches drawn from ecosystem theory. A recent example, presented by Lestelle et al. (1996), uses salmon as an indicator species for ecosystem health. Like watershed analysis, this type of method works to integrate watershed processes, population dynamics and the effect of management actions. Another ecosystem approach is a "limiting factor analysis," which attempts to identify which habitat component constrains or limits the size of a population. An example of a limiting factor analysis method is presented by Reeves et al. (1989) and discussed in the "Use of an Expert System" section, above. Like population modeling, the topic of integrating ecosystem approaches and watershed analysis is too large to address in the module.

A strength of an ecosystem approach is that it builds on past research and integrates many of the dynamic factors that limit populations. One difficulty with this type of approach is that information requirements and analysis may become very complex.

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Form AL1. Summary of hypotheses

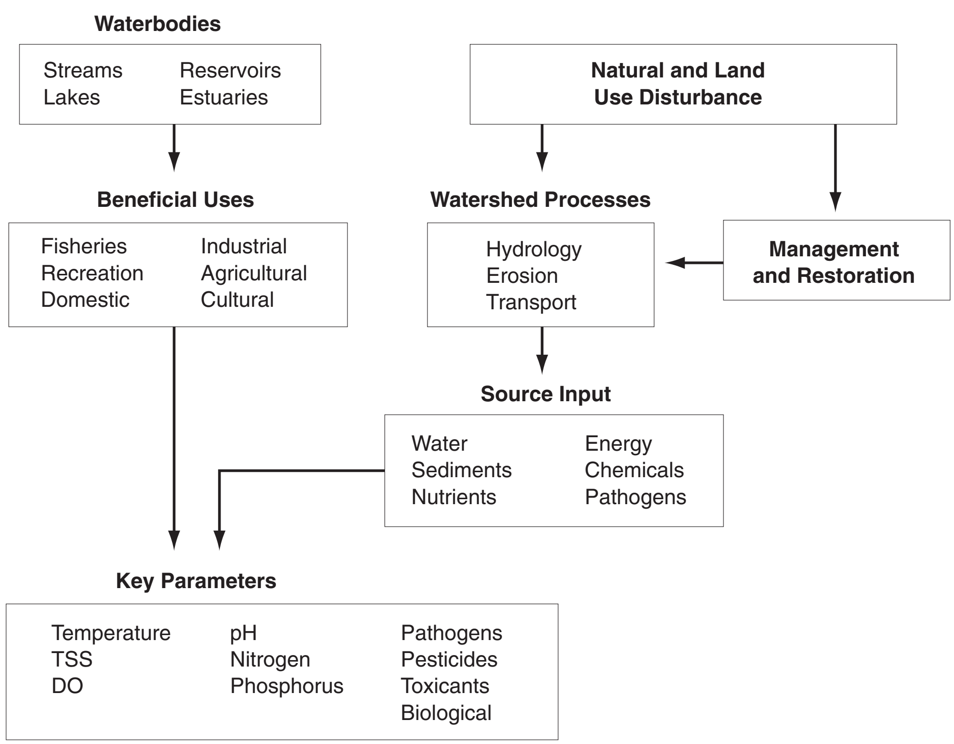
Species	Sub-basin	Description	Hypothesis	Source (include watershed expert as appropriate)

Water Quality

Background and Objectives

The goal of the Water Quality assessment is to evaluate the status of specific waterbodies as reflected by various water quality parameters related to the health of community resources (Figure 1). The evaluation process will not only aid in identifying existing water quality problems but will also identify the possible sources that may have caused the problems and suggest changes in management practices or restoration possibilities.

Figure 1. Water quality assessment



Regional Interagency Executive Committee (RIEC) and Intergovernmental Advisory Committee (IAC) (1995)

Level 1 Water Quality assessment is a screening process that characterizes the status of water quality in the watershed and identifies potential sources of impacts. The assessment can also identify which waterbodies are at risk and where more in-depth assessment is needed to address specific pollution problems.

Level 2 Water Quality assessment can be conducted for stream segments or waterbodies that have been identified as impaired by the Level 1 assessment or that are on the State

303(d) list. Level 2 assessment provides detailed examination of pollution sources and a complete description of water quality problems. Targeted stream sampling plans may be developed to pinpoint pollution sources and provide quantitative information on the degree of impact from a specific source. Level 2 assessment is also helpful when a higher level of certainty is required, such as when developing TMDLs or restoration strategies.

Water Quality Module Reference Table

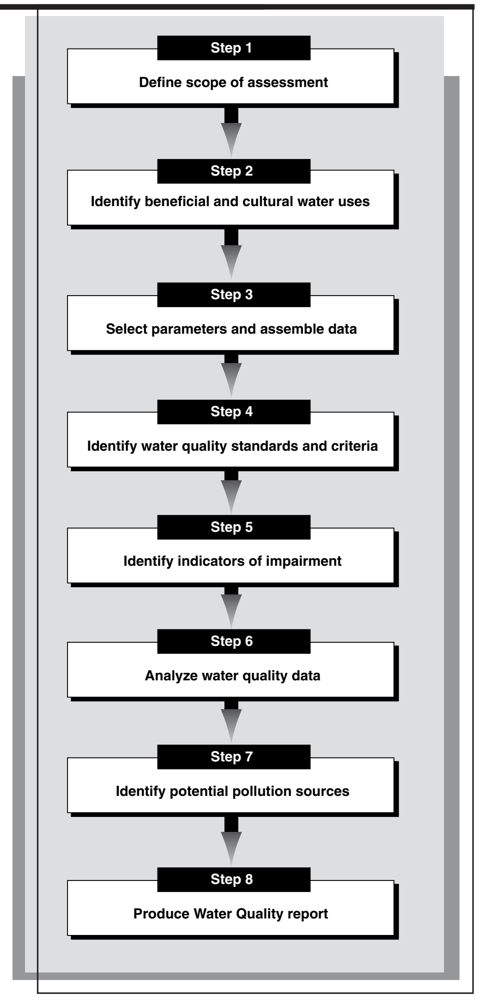
Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
WQ1: What are the beneficial uses of water resources?	• State, tribal, and local documentation	• Survey community members • Interview government agencies	
WQ2: What water quality parameters have not met the standard and for what time period?	• 303d list • EPA, state, and tribal standards • Monitoring data • Additional information required for modeling	• Compare the available data to standards • Trend analysis	• Statistical analysis • Modeling • Additional monitoring • Toxicity test
WQ3: How much difference exists between current water quality and reference conditions?	• Map and other description of the reference conditions • 303d list • EPA, state, and tribal standards • Monitoring data	• Summarize and compare available data • Describe the reference conditions • Survey various users	• Field surveys • Monitoring • Stream classification
WQ4: What causes temperature impairment?	• 303d list • Change in water and land use • NPDES data • Weather data • Flow data • Aerial photos of riparian conditions • Stream characterizations	• Identify possible point and non-point sources • Identify diversions and new water uses • Identify land use change and any abnormal climate conditions	• Mixing and heat balance calculations • Computer simulations
WQ5: What causes fish consumption advisories?	• Water quality data, especially PCBs, metals, and organic compounds. • Reports of previous advisories • NPDES data • Fish tissue analysis results • Benthic sediments and pathogens data	• Identify possible point and nonpoint sources • Interview water users	• Toxicity analysis • Bioaccumulation analysis
WQ6: What causes fish kills?	• DO, temperature • Chemical spills, and mining activities • Fish species • Stream characteristics • Nutrient concentrations • Flow data • pH	• Compare water quality data to available standard for the fish species • Identify potential pollutant sources affecting fish survival	• Computer simulation for dynamics of DO, temperature, pH, and algae
WQ7: What causes excessive algae growth or eutrophication?	• NPDES data • 303d list • Land uses • Data on nitrogen and phosphorus concentrations • Temperature • Turbidity • Flow • Chorophyll-a • Solar radiation	• Examine data for excessive nutrient concentration and aquatic weeds • Identify potential nutrient sources	• Predict primary productivity • Computer simulations

Water Quality Module Reference Table (continued)

Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
WQ8: What can cause beach or swimming area closures and other pathogen problems?	• Data from Health Department • Beach locations • Livestock facilities and septic systems • Flow data • Hydrological data • Pathogen attenuation rates	• Identify potential pathogen sources of agricultural and urban origin.	• Pathogen die- off and transport calculation • Computer simulations
WQ9: What conditions lead to excessive turbidity?	• Land use and soil type data • Urban construction sites • Road data • Agricultural practices • Wind data • Hydrological data • Watershed characteristics		• Erosion and sediment delivery models • WEPP, RUSLE and other computer simulation models
WQ10: What causes foul odors?	• NPDES data • Industrial facilities • Livestock production facilities • Water surface change • DO • Flow rate • Volatile compound	• Identify sources such as industrial processes, wetlands, wastewater treatment plants, failed septic systems	• Calculate volatilization rate • Identify odorous substances
WQ11: What adverse impacts on wetlands might have resulted from water quality impairments?	• Data on sediments, nutrients, and toxic chemicals • Water balance • Water temperature • Change in water salinity	• Mapping historical and existing wetland areas • Evaluate changes in vegetation sensitive to water quality	• Modeling and computer simulations • Additional water analysis for toxic substances
WQ12: What are the other possible major sources causing water quality problems?	• Acid mine drainage • Chemical spills • Irrigation return flows • Landfill sites • Connection to storm sewer • Leaking underground storage tanks • Atmospheric deposition • Acid rain • Groundwater • Monitoring data	• Identify locations of the potential sources	• Pathway analysis • Additional monitoring • Modeling and computer simulation • Examine land fill records • Check irrigation flow quality data

Background and Objectives

Step Chart



Data Requirements and Sources

Data requirements

The following is a brief list of the data required to begin the Water Quality assessment. Some of the maps and data may not be available for a given watershed or may not be necessary depending on the scope of water quality issues.

- USGS topographic map of the watershed (1:24,000 scale).
- GIS stream layer (if available).
- Copies of existing water quality data and reports.
- 305(b) list reports and inventories of state waterbodies.
- 303(d) list of state waterbodies not in compliance with the Water Pollution Control Act of 1972 (Clean Water Act [CWA]).
- NPDES permit compliance data for point source discharges.

Data sources

There are numerous sources of water quality data currently available, and access to the web has greatly facilitated the distribution of information (Tables 1 and 2). Water quality information may be accessed in different forms, such as raw data, databases, and reports. Reports and databases generally prove to be better sources than simple raw data. Reports offer the advantage that previous synthesis and analysis efforts have been made. Details on how the data were collected may also be provided. Most commercial databases are compiled based on the original data collected with QA/QC protocols. Although raw data may be available locally, it will most likely need to be processed before analysis.

Table 1. Internet sources for water quality information

Web site	Web address	Description
EPA Surf Your Watershed	http://www.epa.gov/surf2	• Location of watershed • Assessment of watershed health • State and tribal Unified Watershed Assessments and contacts • EPA regulated facilities and pollutant discharges • Links to community groups
EPA Unified Watershed Assessments	http://www.epa.gov/cleanwater/uwafinal/appc.html	• Links to and descriptions of federal programs for collecting water quality information
EPA and NRCS Clean Water Action Plan	http://www.epa.gov/cleanwater/links.html or http://www.nhq.nrcs.usda.gov/cleanwater/links.html	• Links to federal, state, and private sites with environmental data and other information
EPA STORET	http://www.epa.gov/owow/storet/	• Large national database of water quality information
USGS Water Resources Data	http://water.usgs.gov/data.html	• Links to water flow, water quality, and climate data
USGS National Water Quality Assessment Program	http://water.usgs.gov/nawqa/nawqa_home.html	• Describes the status and trends in the quality of the nation's groundwater and surface water resources
USGS National Mapping Program	http://mapping.usgs.gov/	• Contains topographic maps, spatial data, and remote sensing data
Association of State and Interstate Water Pollution Control Administrators	http://www.asiwpca.org	• Links to state water quality programs
NRCS National Resources Inventory	http://www.nhq.nrcs.usda.gov/NRI/	• Statistically-based sample of land use and natural resource conditions and trends on non-federal lands in the United States

Products

- Form WQ1. Summary of water quality conditions
- Map WQ1. Water quality impairments
- Water Quality report

Procedure

The objectives of the Water Quality assessment are as follows:

- To identify the beneficial and cultural uses of water resources.

Table 2. Local sources of water quality information

Data Source	Description
State 303(d) and 305(b) reports	• 303(d) reports list water quality impaired waterbodies and parameters exceeding standards. • 305(b) reports characterize general water quality conditions and programs to restore and protect waters.
Section 314 and 319 lists	• Section 314 lists indicate the water quality status of public lakes, including point and non-point source pollution problems. • Section 319 lists were created in 1989 and characterize water quality problems in coastal areas.
State and local soil conservation districts	• Expertise and information may be available on the effects of agricultural practices such as grazing, irrigation, and waste management.
State and tribal health departments	• Expertise and information may be available on drinking water, septic tanks, and community health.
University libraries	• Unpublished reports, dissertations, and theses may be available in science and engineering libraries.

- To summarize water quality parameters related to the resource uses.
- To assess the trends and status of important water quality parameters.
- To identify sources of water quality impacts.

Step 1. Define scope of assessment

Identify the key personnel and assign responsibilities for the Water Quality assessment team. Team members may be from within the lead tribal organization or may consist of external community members or experts.

A preliminary plan of action should be developed that succinctly defines the assessment objectives. The stream segments or sub-basins to be assessed, general time-frame for completion, anticipated data collection problems, and responsibilities for final products should all be discussed. Collecting, analyzing, and reporting water quality data that have very little or no impact on the Water Quality assessment can waste a significant amount of time.

Step 2. Identify beneficial and cultural water uses

Identify all legally defined beneficial uses and other potential beneficial uses (e.g., cultural) of the water resources within the watershed. The beneficial use of each stream segment

Table 3. Examples of beneficial uses and related water quality parameters

Beneficial use categories	Key pollutant parameters
Fish and wildlife	TSS Turbidity DO Toxic chemicals Temperature Bacteria
Agriculture	TSS Toxic chemicals
Public water supply	TSS Turbidity Toxic chemicals Bacteria
Navigation	Sediments
Industry	TSS Turbidity
Hydropower	Turbidity TSS/sediment yield
Recreation	Turbidity (aesthetics and safety) Bacteria

EPA (1994)

should be identified from the mouth of the mainstem upstream to the tributaries. A list of federally recognized beneficial uses is shown in Table 3. Beneficial uses should be listed in Form WQ1.

After determining the beneficial uses currently assigned to each stream segment in the watershed, the Water Quality assessment team can begin to discuss whether these designations make sense given the team's knowledge of the watershed. The key questions in Box 1 are a useful guide to ensure that all relevant issues are addressed during this step.

The CWA directed states to establish water quality standards related to the intended uses (or beneficial uses) of surface waters. Some states have completed beneficial use status and attainability assessments for various rivers. The beneficial uses outlined in the CWA do not include cultural or ceremonial water uses, but the CWA does allow flexibility in identifying new uses or biota categories. The analyst should coordinate with the Community Resources and Historical Conditions analysts to identify potential beneficial uses of cultural significance. Establishing new beneficial uses will often require supporting documentation of the following:

Community Resources
Historical Conditions

- Historical use.
- Locations of cultural significance.
- Cultural use protection standards.

Box 1. Key questions for beneficial use identification

- Where are the surface waters, lakes, ponds, estuaries, groundwater aquifers, wetlands, etc.?
- What are the current identified beneficial uses?
- What are the historical beneficial uses?
- What are the key parameters related to the beneficial uses?
- Were any of the beneficial use changes caused by water quality?

Step 3. Select parameters and assemble data

Select water quality parameters

Based on the identified beneficial and cultural uses, determine which water quality parameters will need to be evaluated. Tables 4 and 5 list parameters that typically need to be evaluated for a variety of beneficial uses; the importance of each parameter for each use is rated High, Moderate, or Low.

The parameters for which data are most commonly required are as follows:

- Temperature.
- Total suspended solids (TSS).
- Dissolved oxygen (DO).
- pH (acidity).
- Nutrients (e.g., nitrogen and phosphorus).
- Pathogens (e.g., fecal coliforms).
- Pesticides.
- Metals (e.g., cadmium, chromium, copper, lead, mercury, and zinc).
- Other toxic chemicals.
- Biological conditions.

More extensive definitions of these parameters can be found in introductory water quality texts. The relationships between parameters and community resources are briefly described in the following sections.

Temperature

Elevated stream temperatures can stress and cause behavioral changes in fish populations and other biota. Warmer water temperatures can change aquatic community assemblages, reduce growth rates, and increase disease.

Although land use impacts generally elevate stream temperatures, vegetation removal may cause cooler water temperatures during the winter. Cooler winter water temperatures may reduce growth of fish and can also cause the formation of anchor ice that smothers aquatic life in the stream substrate.

Temperature can also affect a number of other important water quality parameters. Gas solubility decreases with increasing temperature, resulting in generally lower DO

Table 4. Parameter selection for water quality assessment in relation to water uses

Variables	Background monitoring	Aquatic life and fisheries	Drinking water sources	Recreation and health	Irrigation	Livestock watering	Power generation	Iron and steel	Pulp and paper	Food processing	Petroleum
Temperature	H	H		L				H	L		
Color	M		M	M					L	M	
Odor			M	M						H	
Suspended Solids	H	H	H	H			M	M	L	M	H
Turbidity	L	M	M	M					M	M	
Conductivity	M	L	L		L						
Total dissolved solids		L	L		H	L	H	M	H	H	L
pH	H	M	L	L	M		H	M	M	H	H
DO	H	H	L		L		L	H	L		
Chlorophyll a	L	M	M	M							
Ammonia	L	H	L				L			L	
Nitrate/Nitrite	M	L	H			M				M	L
Phosphorus	M								L		
Total organic carbon	M		L	L							
Chemical oxygen demand	M	M					M				
Biochemical oxygen demand	H	H	M								
Sodium	L		L		H						
Potassium	L										
Calcium	L				L	L	H		L	L	H
Magnesium	M		L				L		L	L	H
Chloride	M		L		H		M	M	L	H	H
Sulphate	L		L			L	M	M	M	H	L
Fluoride			M		L	L					
Boron					M	L					
Cyanide		L	L								
Metals		M	H		L	L	L		L	M	
Arsenic/Selenium		M	M		L	L					
Oil and Hydrocarbons		L	M				L	L		L	H
Organic Solvents		L	H							L	
Phenols		L	M							L	
Pesticides		M	M							L	
Fecal Coliforms			H	H	H						
Total Coliforms			H	H	L						
Pathogens			H	H	L	M				H	

Chapman (1996)

Table 5. Parameter selection for water quality assessment in relation to additional water uses

Variables	Municipal wastewater	Urban runoff	Agriculture	Solid waste	Atmospheric transport	Textiles	Chemical pharmaceutical	Machine production
Temperature	L	L	M			L	L	L
Color	L	L	L	L		L	L	L
Odor	M	L	M			L	L	L
Suspended Solids	H	M	H	M		H	L	H
Turbidity								
Conductivity	M	M	M	H	H	H	L	H
Eh	L	L	L			L	L	L
pH	L	L	L	M	H	L	H	L
Dissolved Oxygen	H	H	H	H		H	H	L
Hardness	L	L	L		L	L	L	L
Ammonia	H	M	H	M		L	M	L
Nitrate/Nitrite	H	M	H	M	H	L	M	L
Phosphorus	H	M	H	L	L	L	M	L
Total organic carbon	L	L	L			L	M	L
Chemical oxygen demand	M	M	L	H		L	H	L
Biochemical oxygen demand	H	M	H	H		H	M	L
Sodium	M	M	M			L	L	
Potassium	L	L	L			L	L	
Calcium	L	L	L			L	L	L
Magnesium	L	L	L			L	L	
Chloride	H	M	H	M		H	M	L
Sulphate	L	L	L		H	L	M	L
Fluoride	L	L				L	M	
Boron			L			L	L	L
Cyanide						L	L	L
Metals	M	M	M	H	L	M	M	H
Arsenic/Selenium		L	H	L	L	L	L	L
Oil and Hydrocarbons	M	H		M		L	M	H
Organic Solvents	L	L		H		L	H	L
Phenols	L			M		L	H	
Pesticides		L	H	M	H		H	
Fecal Coliforms	H	M	M	H				
Total Coliforms	H							
Pathogens	H		M	H				

Chapman (1996)

concentrations and reaeration rates. With temperature increases, chemical and biochemical reaction rates typically increase markedly and mineral solubility increases. Most organisms have distinct temperature ranges within which they can reproduce and compete effectively.

Total suspended solids (TSS)

TSS are defined as the particles in the water column that are larger than 2 microns in diameter. In streams, the majority of TSS are fine sediments or algae. Laboratory procedures for measuring TSS involve time-consuming processes of filtering, drying, cooling, and weighing. Because TSS can be related to the turbidity of the water, turbidity is used in many cases to evaluate the concentration of fine particulate material suspended in the water column. Turbidity can be quickly measured by determining light transmission in water.

Sediment may directly affect fish by causing gill abrasion or fin rot. Sediment can indirectly impact aquatic biota by reducing habitat through blanketing of fish spawning and feeding areas, by eliminating sensitive food organisms, or by reducing sunlight penetration to aquatic plants, thereby impairing photosynthesis.

Suspended sediment also decreases recreational values, adds to the mechanical wear of water supply pumps and distribution systems, and adds to treatment costs for water supplies. Suspended sediment may also provide a mechanism for transport of pesticides or other toxic compounds.

Dissolved oxygen (DO)

DO is defined as the amount of oxygen dissolved in water. The presence of oxygen is of fundamental importance in maintaining aquatic life and the aesthetic quality of waters. Low DO concentrations may harm fish and aquatic biota. Fish tolerance of low DO levels varies by species, growth cycle, acclimation time, and temperature. Cold water fish (e.g., salmon and trout) require higher DO concentrations than do warm water fish and biota. The preferred DO level for trout is generally greater than 5 mg/L. Rough fish such as carp and catfish can survive at oxygen levels as low as 2 mg/L and also tolerate warmer water.

pH (acidity)

pH represents the concentration of hydrogen ions in water and thus indicates the acidity of the water. As water becomes more basic, pH increases; as water becomes more acidic, pH decreases. pH affects the reaction and equilibrium relationships of many chemicals. Many biological systems function only in relatively narrow pH ranges (typically 6.5 to 8.5). Fish and other aquatic species prefer a pH near neutral (7) but can withstand a pH in the range of about 6 to 8.5. Low pH in water inhibits enzymatic activity in aquatic organisms. The toxicity of many compounds can also be altered if the pH is changed. The solubility of many metals, as well as other compounds, is affected by pH, resulting in increased toxicity in the lower pH range.

Nutrients—phosphorus and nitrogen

Both phosphorus and nitrogen are essential nutrients for the growth of aquatic vegetation. Phosphorus is essential for the growth of algae and other aquatic organisms. Serious problems such as algae blooms and fish kills have resulted when excess phosphorus exists in the aquatic environment.

Nitrogen is a complex element that can exist in seven states of oxidation. From a water quality standpoint, the nitrogen-containing compounds that are of most interest are organic nitrogen, ammonia, nitrate, and nitrogen gas. Table 6 summarizes the generally reported forms of nitrogen.

Table 6. Summary of nitrogen forms

Total Nitrogen				
Total Inorganic			**Total Organic**	
		Total Kjeldahl Nitrogen (TKN)		
Nitrogen	Nitrate	Ammonia	Dissolved	Particulate
Readily available for aquatic plant growth			Must undergo microbial degradation to become available	

Nutrient enrichment of surface waters may cause excessive algae and aquatic plant growth. This creates large diurnal oxygen fluctuations due to excessive DO production during daylight hours followed by excessive consumption of oxygen (mainly through plant die-off) when photosynthesis is not occurring. Seasonal die-off of vegetation due to frost may also create large oxygen demands and suffocate fish and aquatic organisms. Physical impediments to fishing and boating and operation of water supply facilities can also be affected when vegetation becomes so overgrown that leaves and roots clog motors and intakes. Nitrate contaminants in drinking water significantly above the drinking water standard (10 mg/L) may cause methemoglobinemia (a blood disease) in infants and have forced closure of several water supplies. High ammonia concentrations in water are also toxic to fish and cause an odor problem.

Pathogens

Pathogenic bacteria, protozoa, and viruses include infectious agents and disease-producing organisms normally associated with human and animal wastes. Waterborne pathogens can be transmitted to humans or animals through drinking water supplies, direct contact recreation, or consumption of contaminated shellfish. Bacterial pathogens of concern include *V. cholerae*, *Salmonellae*, and *Shigella*. Pathogenic protozoan eggs and cysts have been linked to *Giardia lambia* and *Entamoeba histolytica* (amoebic dysentery). Viruses ingested from water can lead to diseases such as hepatitis (Thomann and Mueller 1987).

Detection methods for pathogenic bacteria are severely limited because of the difficulty in isolating a small number of cells. Consequently, in spite of problems establishing direct correlations, coliform groups can serve as indicators of pathogens. Fecal coliform bacteria behave similarly to common enteric pathogens, and a close relationship exists between the growth and survival of fecal coliform and both *Salmonella* and *Shigella*.

Relationships between the total coliform bacteria group and pathogens are not considered to be quantitative. Because of the occurrence and interference of nonfecal bacteria and their differential resistance to chlorination, more accurate approaches involving the fecal coliform and fecal *Streptococci* groups are required.

Pesticides

Pesticides are most commonly used in agricultural applications for the control of weeds and pest organisms. The presence of these substances in water is troublesome because they are toxic to most aquatic organisms and many are known or suspected carcinogens. Potential impairments from pesticides include damage to aquatic fauna and concerns for human health (contamination of domestic water supply or fishery). Concentration levels rather than overall loadings are most important. Contamination of groundwater by organic chemicals can occur through leaching.

Metals

Heavy metals are a group of elemental pollutants including arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc. Industries such as electroplating, battery manufacturing, mining, smelting, and refining have been identified as potential sources of heavy metals. Metals may enter surface waters either dissolved in runoff or attached to sediment or organic materials. Metals can also enter groundwater through soil infiltration.

Metals can have toxic effects on humans, fish, wildlife, and microorganisms. Since metals do not readily decay, their persistence in the environment is a problem potentially contributing to long-term habitat and public water supply degradation. A principal concern about metals in surface water is their entry into the food chain at relatively low concentrations and their bioaccumulation over time to toxic levels. High concentrations of arsenic can cause dermal and nervous system toxicity effects; high concentrations of cadmium can cause kidney effects; and high concentrations of chromium have been linked to liver and kidney effects. Lead can result in central nervous system damage and kidney effects and is also highly toxic to infants and pregnant women. High concentrations of mercury can cause central nervous system disorders and kidney effects; high concentrations of selenium have gastrointestinal effects; and high concentrations of silver can cause skin discoloration.

Other toxic chemicals

Thousands of industrial and petroleum processing chemicals such as plasticizers, solvents, waxes, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) make up the final group of toxic substances. Alkyl phthalates, chlorinated benzenes, PCBs, and PAHs are broad subcategories in this group. Some chemicals are carcinogenic directly to humans, while others affect fish, aquatic organisms, or plants within the water column or in the benthic sediment layer.

Biological conditions

Because water quality problems often manifest themselves in terms of fish or organism health, many states and the EPA are promoting data collection on fish and benthic organism communities while conducting water quality assessments. While biological data are generally considered to be indicators of water quality rather than specific parameters, it may be cost-effective to compile this data and water quality data simultaneously. The biological data may be critical in associating pollutant concentrations with long-term detrimental effects. However, a great deal of uncertainty exists when interpreting this type of data.

Assemble water quality data

Assemble all of the relevant water quality data available for the watershed. It is very important to keep the assessment objectives in mind to keep the team focused. Try to avoid collecting information outside the scope of the project.

Identify data deficiencies
Problems exist when comparing data sets collected by different entities. For example, the data may have been collected using different methodologies and QA/QC protocols or at different times and locations. To facilitate the combination of data from various sources, team members will need to become familiar with the designation of stream segments and waterbodies within their watershed.

An important part of creating the database will be judging the validity of the data. Laboratory errors, data translation errors, improper chain of custody procedures, and several other independent sources of error can affect results. Undoubtedly, data interpretations will need to be made, but they should be made carefully by experienced professionals.

Step 4. Identify water quality standards and criteria

Identify existing water quality standards and criteria applicable to the waterbodies and stream segments being assessed. Water quality standards are laws or regulations adopted by states and tribes to enhance water quality and to protect public health and welfare. Water quality standards provide the foundation for accomplishing two of the principal goals of the CWA: 1) to restore and maintain the chemical, physical, and biological integrity of the nation's waters, and 2) where attainable, to achieve water quality that promotes protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water (EPA 1999).

A water quality standard consists of three elements: 1) the designated beneficial use or uses of a waterbody or segment of a waterbody, 2) the water quality criteria necessary to protect the use or uses of that particular waterbody, and 3) an antidegradation policy. Water quality criteria describe the quality of water that will support a designated use and may be expressed as either quantitative limits or a qualitative description. In practice, criteria are set at levels that will protect the most sensitive of uses, such as human health or aquatic life. An antidegradation policy ensures that water quality improvements are conserved, maintained, and protected (EPA 1999).

Water quality criteria can be obtained from a wide range of sources:

- EPA criteria.
- State water quality criteria.

- Site-specific criteria based on scientific studies.
- Agency guidelines.

Table 7 is an example of EPA water quality criteria. The term biota is fairly comprehensive, so there may be scientifically justifiable reasons for requiring more or less stringent criteria for a particular species than those shown in the table. Table 8 provides regional reference values for natural water quality derived from 57 stations constituting the National Hydrologic Benchmark Network.

Not all criteria have been translated into state or local laws; however, some agencies develop policy based on criteria. A tribe or local health department, for example, may regulate beach closures based on fecal coliform criteria without a specific water quality standard.

Table 7. EPA water quality criteria for DO concentrations (mg/L)

	Cold water biota		Warm water biota	
Period	Early Life Stages	Other Life Stages	Early Life Stages	Other Life Stages
30-day mean	NA	6.5	NA	5.5
7-day mean	9.6 (6.5)*	NA	6.0	NA
7-day minimum	NA	5.0	NA	4.0
1-day minimum	8.0 (5.0)	4.0	5.0	3.0

* Applies to species that have early life stages exposed directly to water column.

Novotny and Olem (1994)

Table 8. Regional reference values for regional natural water quality

	Region				
Parameter	Eastern	Midwest	Great Plains	Mountain	Pacific
TSS (mg/L)	5-10	10-50	20-100	5-20	2-5
BOD (mg/L)	1.0	1-3	2-3	1-2	1
Nitrate (mg/L)	0.05-0.2	0.2-0.5	0.2-0.5	0.1	0.05-0.1
Total Phosphorus (mg/L)	0.01-0.02	0.02-0.1	0.1-0.2	0.05	0.05-0.1
Total coliforms (MPN/100 ml)	100-1000	1000-2000	500-2000	100	100-500

Novotny and Olem (1994)

Step 5. Identify indicators of impairment

Water quality impairment is typically defined as the exceedence of criteria, but other indicators of problems, such as fish kills, algae blooms, and localized epidemics, should also be examined. For each waterbody or stream segment, record potential indicators of impairment on Form WQ1.

Numerous studies have been conducted to determine the precise combination of water quality indicators necessary to accurately assess watershed conditions (EPA and USFWS 1984, Heaney 1989, Greeley-Polhemus Group 1991). Snodgrass et al. (1993) present a sub-basin framework for managing environmental quality where flooding, erosion, surface water quality, groundwater (quality and quantity), natural features (wetlands), aquatic communities, recreation, aesthetics (water, valleyland), terrestrial (wildlife, woodlots), and receiving waterbody issues are examined. Each category could be further divided to coincide with the available data if additional clarification were needed. The EPA (1996a) identified 18 environmental water quality indicators to meet five national environmental goals. These indicators reflect the requirements of both the CWA and the Safe Drinking Water Act. However, many of the indicators comprise multiple parameters whose relative significance has yet to be established.

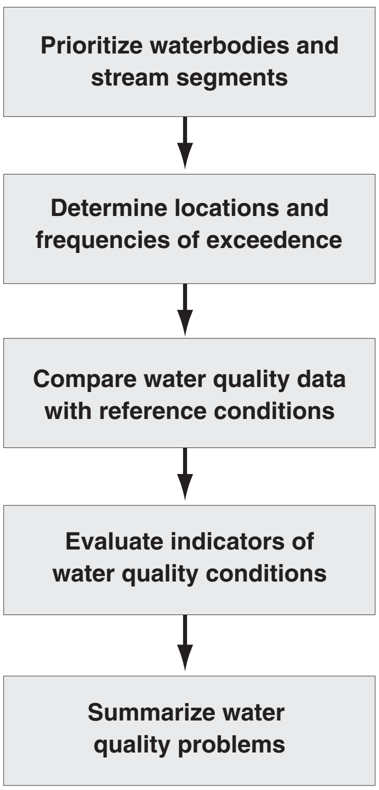
The EPA (1995a) used environmental indicators to judge the effectiveness of stormwater management efforts. The indicators were selected from categories such as 1) water quality, 2) physical and hydrological, 3) biological, 4) whole watershed, 5) social, 6) programmatic, and 7) site-specific compliance. Unfortunately, monitoring many of these indicators would be cost-prohibitive.

Biological indicators have received considerable attention in recent years as potential markers of watershed health. However, interpreting the results of bioassessment studies can be difficult. Organism populations and community structures can vary considerably according to season and site, making it difficult to interpret fluctuations.

Step 6. Analyze water quality data

Analyze the water quality data obtained in Step 1 and compare the data with the standards and criteria identified in Step 2 to assess whether the existing water quality can support the beneficial and cultural uses identified in Step 3. In some cases, evaluation of exceedences may only require comparison of monitoring data to established standards and criteria. In more complicated watersheds, the assessment team might have to evaluate the quality of the data, perform statistical analyses, or suggest possible standards or criteria. The major tasks of this step are illustrated in Figure 2. The key questions listed in Box 2 will help guide the Water Quality assessment team during the data analysis phase.

Figure 2. Major tasks in water quality data analysis



Level 1 assessment involves basic statistical analyses to describe the central tendency and spread of water quality data. The mean or median describes the central tendency of the sample, while the standard deviation or interquartile range measures the spread of data from the mean. Analysts can refer to several documents for more detailed descriptions of statistical procedures (Gilbert 1987, MacDonald et al. 1991, EPA 1997a).

Prioritize waterbodies and stream segments
Decide which waterbodies or stream segments require more detailed water quality evaluations. Contact other members of the assessment team, such as the Aquatic Life or Channel analyst to identify critical areas. Reports that summarize water quality data and concerns, such as the state 305(b) reports, can also help to focus the assessment.

Aquatic Life
Channel

Box 2. Key questions for water quality data analysis

- In what sequence should the waterbodies be analyzed?
- How were the standards set up, (e.g., based on monthly or weekly mean concentration)?
- Is the water quality data format consistent with the standard?
- What water quality parameters have not met the standard and for how long?
- What beneficial uses are not supported in the waterbody?
- What are relevant background or reference conditions for the waterbodies of interest?
- How different is the existing water quality from the reference conditions?

Determine locations and frequencies of exceedences

Review water quality data to identify exceedences of water quality criteria. Water quality problems can also be identified by referencing water quality–related information such as reports on fish kills, state 303(d) reports, and other reported violations of water quality standards.

The strength and rigor of the quality control should be considered in determining whether or not the exceedence data are conclusive. EPA standards for monitoring should be considered in reviewing the information (EPA 1996b). If monitoring data are inconclusive or suspect because of quality control, care should be exercised in inferring water quality problems.

Compare water quality data with reference conditions

Community Resources
Historical Conditions

Another approach for confirming water quality problems is to compare water quality data to reference conditions, which represent the natural state prior to significant human disturbance. Reference conditions can be identified in watershed areas with minimal human influence. Another option is to use historical data to identify past reference conditions. Data on reference conditions can be extremely valuable in the analysis process to determine the degree of watershed deterioration and the feasibility of maintaining certain beneficial uses. The reference condition approach is particularly useful when water quality standards are not available.

Evaluate indicators of water quality conditions

Community Resources

Using the information on indicators of water quality collected in Step 5, consider whether water quality standards and criteria are sufficient to protect community resources. Identify waterbodies where qualitative indicators such as fish kills, "swimmer's itch," unpleasant odors, or fish consumption advisories suggest impairment of community resources. Consult with the Community Resources analyst to help incorporate observations from the local community.

Aquatic Life

Biological monitoring programs may provide useful information for identifying habitat alterations, the cumulative effects of pollutants, and the biological integrity of aquatic communities. A change in the abundance of organisms or in community composition may indicate problems not revealed by more conventional water chemistry monitoring. Consult with the Aquatic Life analyst about the status and trends of aquatic populations.

Summarize water quality problems

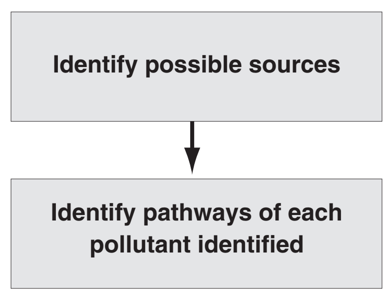
Summarize the water quality problems in Form WQ1 and the Water Quality report. The analysis of water quality exceedences, reference conditions, and impairment indicators should provide the evidence to document water quality problems. Impaired stream segments or other waterbodies should be highlighted on Map WQ1.

Water quality data may not be available or may have significant gaps for many of the parameters. Major gaps in water quality data (e.g., inadequate coverage, infrequent measurements, lack of reliability) should be identified in the Water Quality report. Insufficient standards or criteria to evaluate water quality should also be highlighted.

Step 7. Identify potential pollution sources

Identify the potential sources of the water quality problems found in the watershed. The information can be used as either a basis for further assessment or as a reference for management plans. The general tasks involved in this step are illustrated in Figure 3. Box 3 lists key questions that should be considered during this step. Concluding that a waterbody is at risk from a particular practice often requires explicit evaluation of the hazardous inputs, the transport of pollutants, and delivery to sensitive resources in a Level 2 assessment.

**Figure 3.
Major tasks in pollution source identification**



Box 3. Key questions for pollution source identification

- What are the potential sources of sediment, water, heat, chemicals, pathogens, nutrients, etc.?
- What is the fate of pollutants upon entry to the stream?
- What is the potential for chemical change, dilution or other transformation effects?
- What is the potential for delivery via runoff, infiltration, or atmospheric transport to sensitive segments?
- What is the evidence for cause-and-effect linkages?

Identify possible sources

Develop a list of all possible sources that relate to the water quality impairment, including both point sources and non-point sources. A number of resources may be useful in this part of assessment:

- **Resource Conservation and Recovery Act (RCRA) site data**. Under the RCRA, the EPA evaluates hazardous waste sites for corrective action. Information may be available on toxic sources and risks to resources.

- **NPDES permit data**. State agencies are commonly responsible for implementation of point source discharge permitting under the CWA. Under this authority, states provide permits to pollutant dischargers based upon a review of receiving water assimilation capacity, loading, and other considerations.

- **Stormwater evaluations**. County and city governments commonly conduct analyses of stormwater and associated effects on water quality. This information may indicate pollutant loadings of toxic and non-toxic substances.

- **Health department studies and sanitary surveys**. Health departments (state and county level) commonly evaluate water quality impacts, including the impacts on shellfish beds, groundwater, and surface water.

- **State recreational studies**. State recreation agencies commonly evaluate site qualities with respect to human use potential, as well as the condition of fish and wildlife habitat.

- **Species evaluations by the USFWS and state resource agencies**. Habitat conservation plans and other analyses evaluating habitat and impacting land practices may be on file.

- **Section 319 studies (under the CWA)**. These may include evaluations of water quality problems, inventories, etc.

- **Resource agency studies**. Local, state, and federal agencies that regulate land disturbing activities often have information on land use and potential water quality problems. The NRCS commonly funds conservation districts to evaluate water quality problems specific to agricultural lands. The BLM and USFS often have data on timber sales, grazing allotments, and mining claims that may impact water quality.

Identify pathways of each pollutant identified

Identify the relationship between pollution sources and the water quality problems. A pathway diagram is a useful tool to show the potential links between the source of generation and water quality (Figures 4 - 8 in the "Level 2 Assessment" section). The diagram is a simple way to crystallize the strategy for the assessment and narrow it down to manageable dimensions.

The identification of pathways should be based upon knowledge of pollutant-generating activities, the transport of pollutants, and the location of water quality problems. The Level 2 assessment provides more detailed information on identifying pollutant pathways.

Step 8. Produce Water Quality report

The Water Quality report should summarize water quality conditions, indicators of impairment, and connections between pollutant sources and resource impairment. Highlighting assumptions, gaps in data, and scientific uncertainty in the Water Quality report will be important to evaluate the confidence in the assessment.

The report will typically include the following components:

- Summary of available water quality data.
- Applicable water quality standards and criteria.
- Community resources dependent on water quality.
- Exceedences of criteria and standards.
- Indicators of impairment.
- Potential sources of impairment.
- Conclusions of the assessment.
- Future monitoring and research needs.
- Confidence in the assessment.

Level 2 Assessment

This section provides a general overview of methods and tools that can be used in a Level 2 Water Quality assessment. It is not comprehensive and by no means represents a complete procedure. Sources that provide more detailed information on assessment methods are noted throughout this section.

Level 2 assessment can be complicated by the fact that water quality parameters are often interrelated. Unlike more visible indicators of watershed health, water quality problems often manifest themselves through symptoms that may occur miles downstream of the actual problem. For example, eutrophication problems, caused by excessive phytoplankton growth, require sufficient nutrients, temperature, light, and time. Problems with excessive nutrient inputs upstream may not become evident until after water flows into a lake, where sediments settle, allowing additional light penetration, the water temperature increases, and the algae has time to grow. Investigating the lake for the source of nutrients may prove to be futile because they were transported from upstream sources. This complexity may make characterization or identification of water quality problems very difficult.

Level 2 assessment for water quality can be quite complicated and requires interaction with several of the other module analysts, patricularly the Hydrology, Aquatic Life, and Erosion analysts. Pathway analysis requires knowledge of water chemistry and environmental science. Use of complicated mathematical models requires knowledge of both water quality and computer modeling, and extensive training and experience may be necessary to use computer simulation packages. In addition, Level 2 assessment may require extensive field data collection at specific locations throughout the watershed. Thus, estimates of the time and resources required for assessment need to take into account these elements.

This section focuses on methods and quantitative tools for estimating pollutant loading from various sources. The methods and tools are divided into four categories:

- Analysis of mixing and dilution.
- Loading tables.
- Parameter-specific pathway analysis.
- Computer simulations.

Analysis of Mixing and Dilution

A mixing and dilution calculation is the most widely used method for evaluating the impact of a pollutant discharge on a receiving waterbody. The pollutant from a particular source is typically diluted after being discharged. The impact of the discharge can be evaluated by determining the pollutant concentration in the receiving waterbody after mixing. Conversely, if an elevated pollutant concentration is measured and a source can be identified, then the amount of discharge from the source can be back-calculated. The equation used for these purposes is as follows:

$$C_f = (C_1Q_1+C_2Q_2)/(Q_1+Q_2)$$

Where: C_f = pollutant concentration after mixing.
C_1 and C_2 = pollutant concentrations in the source and the receiving water before mixing, respectively.
Q_1 and Q_2 = flow rates of the source and the receiving water, respectively.

For a lake or a pond without appreciable water exchange, the mixing equation can be written as follows:

$$C_f = (C_1V_1+C_2V_2)/(V_1+V_2)$$

Where: V_1 and V_2 = volumes of the source and the receiving water, respectively.

The resulting pollutant concentration assumes complete mixing of the pollutant and the receiving waterbody. This generally will not occur until some distance downstream. Within the initial dilution zone, concentrations may be considerably higher. The length of the mixing zone can be quite variable depending on stream characteristics and possible density or thermal stratification between the pollutant and the natural stream. Several methods for determining the mixing zone length can be found in the literature. These range from relatively simple rule-of-thumb approaches to computer models such as CORMIX. Analytical solutions can be found for river mixing in references such as Thomann and Mueller (1987) and Martin and McCutcheon (1999). Martin and McCutcheon (1999) also present more in-depth theoretical discussions concerning mixing in streams and lakes.

Loading Tables

Hydrology

When detailed information is not available or time and resources are not adequate to do modeling, proper use of loading tables allows quick estimations of pollutants from a particular source or land use. Loading tables give unit pollutant loading rates. Examples include soil erosion per acre of land, atmospheric deposition per square foot of surface area, and solids product rate per foot of curb length in cities. Table 9 illustrates some approximate loading rates for different land uses in Washington State. Other sources for unit loading values include McElroy et al. (1976), Thomann and Mueller (1987), and Chandler (1993). Novotny and Chesters (1981) include approximations for nutrient export based on geographic regions of the United States and land use. The values are given in terms of concentration, so approximations for runoff must also be made independently.

Table 9. Unit loads of pollutants (kg/ha/yr) from different land uses*

Pollutant	Central business district	Other commercial	Industrial	Single family res.	Multi-family res.	Cropland	Pasture	Forest	Open
TSS	1080	840	56	17	440	450	340	85	7
COD	1070	1020	63	28	330	n.a.	n.a.	n.a.	2.0
Pb	7.1	3.0	2.0 - 7.1	0.1	0.7	0.005 - 0.006	0.003 - 0.015	0.01 - 0.03	n.a.
Zn	3.0	3.3	3.5 - 12	0.22	0.33	0.03 - 0.08	0.02 - 0.17	0.01 - 0.03	n.a.
Cu	2.1	n.a.	0.33 - 1.1	0.03	0.33	0.01 - 0.06	0.02 - 0.04	0.02 - 0.03	n.a.
NO_3+$N0_2$-N	4.5	0.67	0.45	0.33	3.8	7.9	0.33	0.56	0.33
TKN	15	15	2.2 - 15	1.1 - 5.6	3.4 - 4.5	1.7	0.67	2.9	1.7
TP	2.8	2.7	0.9 - 4.0	0.2 - 1.5	1.3 - 1.6	0.1 - 3.0	0.07 - 3.0	0.02 - 0.45	0.06

* Exact values are given where available; otherwise ranges are reported.

Adapted from Horner et al. (1986)

Parameter-Specific Pathway Analysis

Many equations or methods have been developed to analyze the relationship between different forms or phases of pollutants. Pathway analysis explores the relationship between different forms of a pollutant based on the physical or chemical processes of transformation. Knowledge of these relationships will improve identification and evaluation of pollutant sources. The pathway analysis conducted in a Level 1 assessment (Step 7) is often qualitative, aiming at source identification. Pathway analysis conducted in a Level 2 assessment is more quantitative, aiming at identification of the degree of impact from one or more possible sources.

Temperature

The relationship between water temperature and the factors controlling it is well understood and amenable to quantitative prediction. The temperature of a waterbody can be determined by calculating the heat balance between the waterbody and the surrounding environment. Major controlling factors include solar radiation, geographical location, elevation, groundwater interaction, shading, and seasonal weather conditions such as rain and wind.

Land use activities that affect discharge, streamside vegetation cover, and channel morphology all exert variable influences on temperature in different climates. With other factors held constant, streams with lower discharge are more susceptible to temperature increases during the summer and decreases during the winter. Reduction of base flows also causes increased seasonal temperature extremes because groundwater commonly warms streams in winter and cools them in summer.

◀ Hydrology

The reduction of stream surface shading by the removal of riparian vegetation can significantly affect temperature, depending upon elevation, stream hydrology, and groundwater/surface water interaction. Riparian grazing can also aggravate seasonal water temperature extremes by reducing base flows via channel incision or soil compaction. Restoration of riparian soils and vegetation through improved range management is one of the most effective management tools available for increasing summer base flows.

◀ Erosion

Increases in channel width caused by high levels of sediment delivery or loss of bank stability also exacerbate water temperature extremes in winter and summer. In summer, Channel Erosion

vegetation of a given height is less effective in shading wider channels. Wider and shallower channels also have a greater heat load under a fixed energy budget because of the increase in the stream surface area.

Temperature modeling can be conducted in two ways. The first deals with mixing of water that has different temperatures, and the second is based on the heat balance of a control waterbody. The mixing equation presented in the "Analysis of Mixing and Dilution" section, can be used in temperature calculations by substituting temperature (T) for concentration (C). This approach is generally used to estimate temperature impacts from point sources. The heat balance approach, on the other hand, is used widely in computer modeling for evaluating non-point sources. A good example can be found in the QUAL2E user's guide (EPA 1995b).

Total suspended solids (TSS)

Erosion

The major sources of TSS include sediment, algae growth in the waterbodies, and point source discharges. The sediment resulting from agricultural and urban runoff and from streambanks can be estimated using methods provided in the Erosion module. TSS caused by algae growth can be related to the nutrient concentration and productivity of the waterbody. Direct discharge from point sources can be estimated from the NPDES permit data, which are maintained by state agencies. TSS in a waterbody is additive; the concentration of the TSS in a waterbody is the summation of the mass of TSS from different sources divided by the volume of the waterbody. Some portion of the suspended solids will settle.

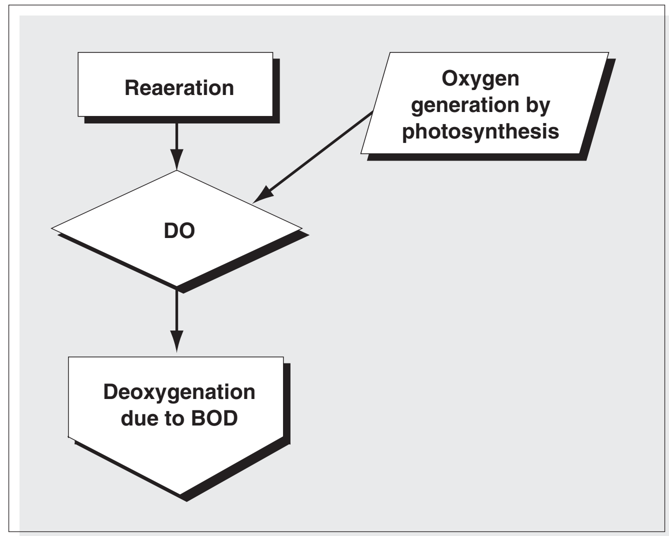
Dissolved oxygen (DO)

The major DO sources include photosynthesis and reaeration (Figure 4). Cool temperature, rapid aeration, and relatively low biochemical oxygen demand (BOD) may increase DO. Respiration of photosynthetic organisms, decay of organic matter in the water column, and benthic oxygen demand decrease DO. Introduction of organic matter from both point and non-point sources to streams can increase BOD and decrease DO. Photosynthetic contributions of oxygen occur only during daylight hours and are quite seasonal. The primary contributors are algae. Highly eutrophic waters may range in DO concentration from supersaturated during hot, sunny days to anaerobic at night.

In mountainous environments, streams possess little vulnerability to low DO because fine organic debris is generally sparse and reaeration of flowing water is more than sufficient to maintain high levels of DO. Low DO is more likely when the following conditions are present:

- Very slow-moving, low-gradient, warm streams with low discharge (i.e., low reaeration rates).
- Heavy inputs of fine organic debris to low-flow streams, causing a large BOD or high concentrations of organics.
- Warm, eutrophic streams, where high rates of photosynthesis and respiration cause diurnal fluctuations in DO (consuming oxygen without reaeration). These conditions are similar to those associated with lake eutrophication.

Figure 4. A simplified pathway of DO



Large BOD is quite often localized to short reaches where organic material accumulates. A second source of BOD demand is the growth of attached organisms, such as the filamentous bacteria often released in wastewater discharges.

In general, risk determination should be based on high organic loading to slow moving streams with limited reaeration potential. Streams subject to warming as a result of low natural flow, water withdrawals, and loss of riparian shade are especially susceptible.

The saturation potential of oxygen depends on the water temperature, the atmospheric pressure, and the salinity. For fresh water at sea level, the DO saturation concentration in mg/L can be expressed as a function of temperature (American Public Health Association 1985):

$$C_s = -139.34411 + \frac{1.575701\ E5}{T} - \frac{6.652308\ E7}{T^2} + \frac{1.2438\ E10}{T^3} - \frac{8.621949\ E11}{T^4}$$

Where: T = temperature in degrees Kelvin ($^{o}C + 273.15$).
C_s = DO saturation (mg/L)

Degradation of pollutants often reduces the DO concentration below the saturation value. The oxidation of carbonaceous substances often causes reduced oxygen levels downstream of point sources. Municipal waste increases BOD, so wastewater treatment plants are a common starting point for this type of analysis. A common tool for predicting DO concentrations under various flow conditions is the Streeter-Phelps Equation. This equation is essentially a balance between DO consumption due to BOD expression and stream reaeration. According to Thomann and Mueller (1987), the DO balance equation can be written as follows:

$$c = c_s - \left\{ \frac{K_d}{K_a - K_r} \left[\exp(-K_r \frac{x}{U} - \exp(-K_a \frac{x}{U} \right] \right\} L_o - (c_s - c_o) \exp(-K_a \frac{x}{U})$$

Where: K_a = reaeration coefficient.
K_d = effective deoxygenation rate.
K_r = BOD loss rate.
x = distance downstream of point source.
U = average water column velocity.
L_o = BOD concentration at the outfall.
c_o = DO concentration at the outfall.
c_s = saturation concentration of oxygen.

pH

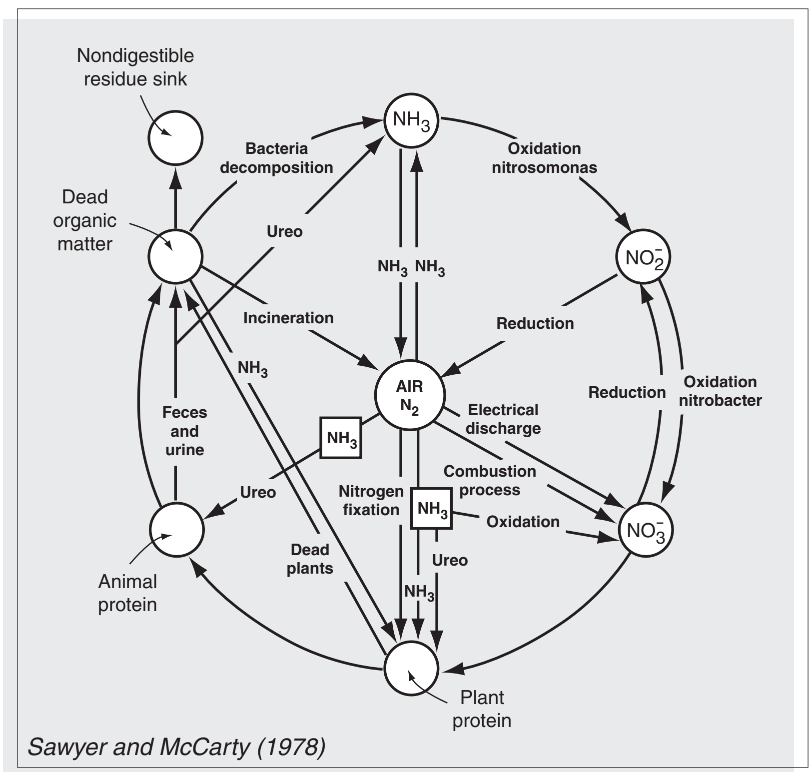
pH modeling involves describing the hydrogen ion balance in water. The natural pH balance of a waterbody can be affected by industrial effluents and atmospheric deposition of acid-forming substances (i.e., acid rain). Changes in pH can indicate the presence of certain effluents, particularly when continuously measured and recorded. Daily variations in pH can be caused by photosynthesis and the respiration cycle of algae in eutrophic water. The rapid growth of algae on a clear day can consume a significant amount of carbon dioxide from the water and increase the pH. During the night, however, the respiration of algae produces excessive carbon dioxide, which lowers the pH.

Nitrogen

In a natural environment, nitrogen undergoes biological and non-biological transformations according to the nitrogen cycle (Figure 5). The major non-biological processes involve phase transformations such as volatilization, adsorption, and sedimentation. The biological transformation involves the following:

1. Uptake of ammonia and nitrate by plants and micro-organisms to form organic nitrogen.
2. Fixation of nitrogen gas by plants and bacteria to produce organic nitrogen.
3. Ammonification of organic nitrogen to produce ammonia during decomposition of organic matter.
4. Oxidation of ammonia to nitrite and nitrate under aerobic conditions.
5. Bacterial reduction of nitrate to nitrous oxide and molecular nitrogen under anaerobic conditions through denitrification.

Figure 5. Nitrogen cycle



Ammonia is highly soluble in water and occurs naturally in waterbodies from the breakdown of nitrogenous organics. Discharges from industrial and municipal wastewater treatment facilities are the most common non-natural sources of ammonia. Ammonia can also result from atmospheric deposition.

In aqueous solution, ammonia occurs in two forms, the un-ionized form (NH_3) and the ionized form (NH_4). The un-ionized form of ammonia is toxic to aquatic life. The ionized ammonia can be adsorbed onto colloidal particles, suspended sediments, and bed sediments. Most reports refer to the concentration of total ammonia nitrogen, which is the summation of the two forms:

$$NH_3 + NH_4 = \text{Total Ammonia Nitrogen}$$

The equilibrium between the two forms is determined by pH; the higher the pH, the more un-ionized ammonia and the higher the toxicity. Unpolluted waters generally contain a small amount of ammonia, usually < 0.1 mg/L as nitrogen. Total ammonia concentrations measured in surface waters are typically less than 0.2 mg/L but may reach 2-3 mg/L. A higher concentration could be an indication of organic pollution such as domestic sewage, industrial waste, or fertilizer runoff. Natural seasonal fluctuations also occur as a result of the death and decay of aquatic organisms, particularly phytoplankton and bacteria in nutritionally rich waters. High ammonia concentrations may also be found in the bottom of lakes that have become anoxic.

Nitrate is an essential nutrient for aquatic plants, and seasonal fluctuations can be caused by plant growth and decay. Under aerobic conditions, ammonia can be biologically oxidized to nitrite and then to nitrate by a group of bacteria called nitrifiers. Under anaerobic conditions with the presence of organic carbon, nitrate can also be reduced to nitrite and then to nitrogen gas. As nitrite is an intermediate product, nitrite concentration in natural waterbodies is usually quite low. Natural sources of nitrate to surface water include igneous rocks and plant and animal debris. Natural concentrations, which seldom exceed 0.1 mg/L, may be increased by municipal and industrial wastewaters, including leachates from waste disposal sites and sanitary landfills. In rural and suburban areas, the use of inorganic nitrate fertilizers can be a significant source. Concentrations in excess of 5 mg/L usually indicate pollution by human and animal waste or fertilizer runoff.

Nitrate is very mobile in soil because of its negative charge. The leaching of nitrate to groundwater can cause groundwater impairments. Increasing groundwater nitrate concentrations in many agricultural regions have been attributed to fertilizer application and animal waste.

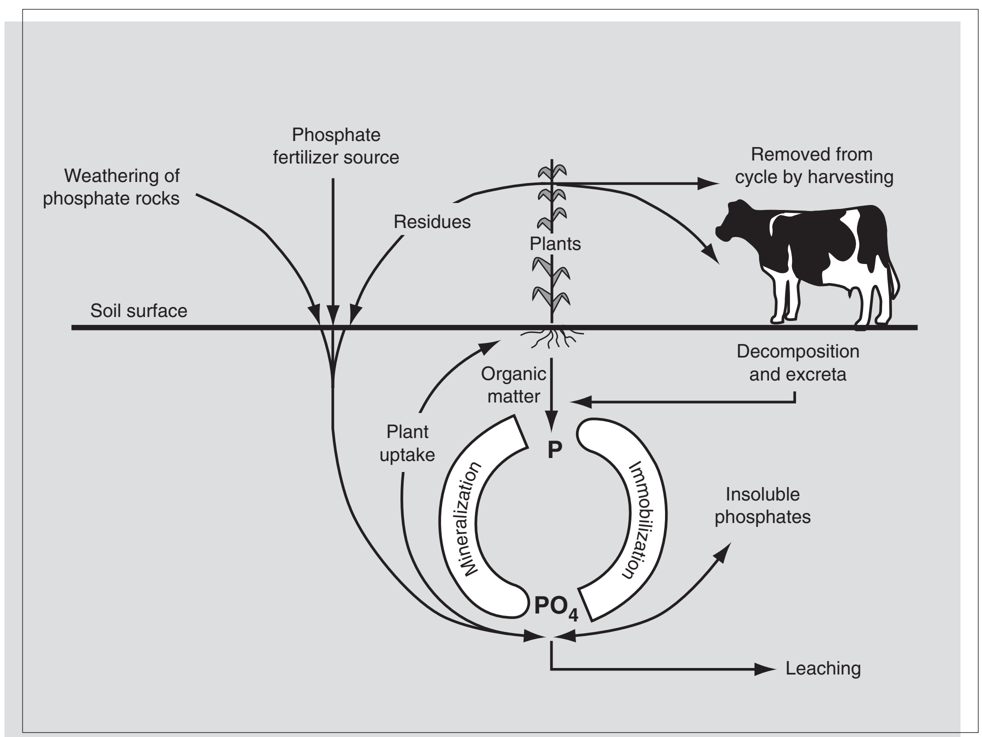
Surface water impairments from nitrogen include eutrophication and toxicity from nitrites, nitrates, and ammonia. Nitrites and ammonia are directly toxic to fish while nitrates and phosphates affect fish indirectly. High nitrate and phosphate concentrations are associated with stream eutrophication. Algae blooms and the profusion of other aquatic plants may directly kill fish when vegetation dies and deoxygenation occurs. Blooms and massive growth of other aquatic plants are possible when nitrate content in the presence of other essential nutrients exceeds 0.5 mg/L.

Most nitrogen transformation processes are evaluated using computer models because of the complexity of the nitrogen cycle caused by the many interactions. The computer simulation models are summarized in a later section.

Phosphorus

Natural sources of phosphorus are mainly derived from the weathering of phosphorus-bearing rocks and the decomposition of organic matter. Domestic wastewater (particularly wastewater containing detergents), industrial effluents, and fertilizer runoff contribute to elevated levels in surface waters. Major pathways of phosphorus transformation include plant uptake, fertilization, and residue decomposition (Figure 6). Unlike nitrogen, phosphorus is not particularly mobile in soils, and phosphate ions do not leach readily. Phosphorus is held tightly by a complex union with clay and soil particulates and organic matter. Most phosphorus is removed from soils either by crop uptake or by soil erosion.

Figure 6. Phosphorus cycle



Phosphorus is rarely found in high concentrations in fresh water as it is actively uptaken by plants. As a result, there can be considerable seasonal fluctuations in surface water concentrations. In most natural surface waters, phosphorus concentrations range from 0.005 to 0.020 mg/L. Concentrations as high as 200 mg/L can be found in some enclosed saline waters (Chapman 1996).

Most phosphorus-related water resource problems result from excessive annual loading. However, if the water resource flushes seasonally, only the phosphorus loading immediately preceding algae bloom periods may be of concern. For instance, runoff from row cropland or suburban developments may be the major phosphorus loading source on an annual basis, but these may be less important than wastewater treatment plant contributions to algae bloom conditions during the summer and early fall.

Phytoplankton growth can be simulated using the following equation:

$$G = G_{max} \frac{x}{K_s + x}$$

Where: G = growth rate based on nutrient limitation.
G_{max} = temperature corrected maximum growth rate.
x = nutrient concentration.
K_S = half saturation constant for nutrient-limited growth.

Pathogens

Bacteria and viruses originate from runoff from livestock areas (Edwards et al. 1997), bottom sediments (Sherer et al. 1988), wildlife (Weiskel et al. 1996), bacterial populations resident in the soil (Crane et al. 1983), septic systems (Weiskel et al. 1996), rural municipalities (Farrel-Poe et al. 1997), and runoff from urban areas (Schillinger and Gannon 1985). Pathogens are largely carried to waterbodies by runoff or sediment transport. Viruses depend heavily on adsorption to sediment particles, while bacteria may be transported to waterbodies by various mechanisms, including infiltration, surface runoff, and adsorption. Pathogens may enter separate storm sewers from leaking sanitary sewers, cross-connections with sanitary sewers, malfunctioning septic tanks, and animal wastes.

Tools used in water quality assessment for pathogens are models for predicting pathogen die-off and transport. Among the factors affecting survival of pathogens are pH, predation by soil microflora, temperature, presence of sediment, sunlight, and organic matter. Tables 10 and 11 present information on some factors that impact pathogen survival.

Table 10. Factors that affect survival of enteric bacteria and viruses in soil

Factor	Type of pathogen	Comments
pH	Bacteria	Shorter survival in acidic soils (pH 3-5) than in neutral and calcareous soils
	Viruses	Insufficient data
Predation by soil microflora	Bacteria	Increased survival in sterile soil
	Viruses	Insufficient data
Moisture content	Bacteria and viruses	Longer survival in moist soils and during periods of higher rainfall
Temperature	Bacteria and viruses	Longer survival at lower temperatures
Sunlight	Bacteria and viruses	Shorter survival at the soil surface
Organic matter	Bacteria and viruses	Longer survival or regrowth of bacteria when sufficient amounts of organic matter are present

EPA (1977) and Novotny and Olem (1994)

Pesticides

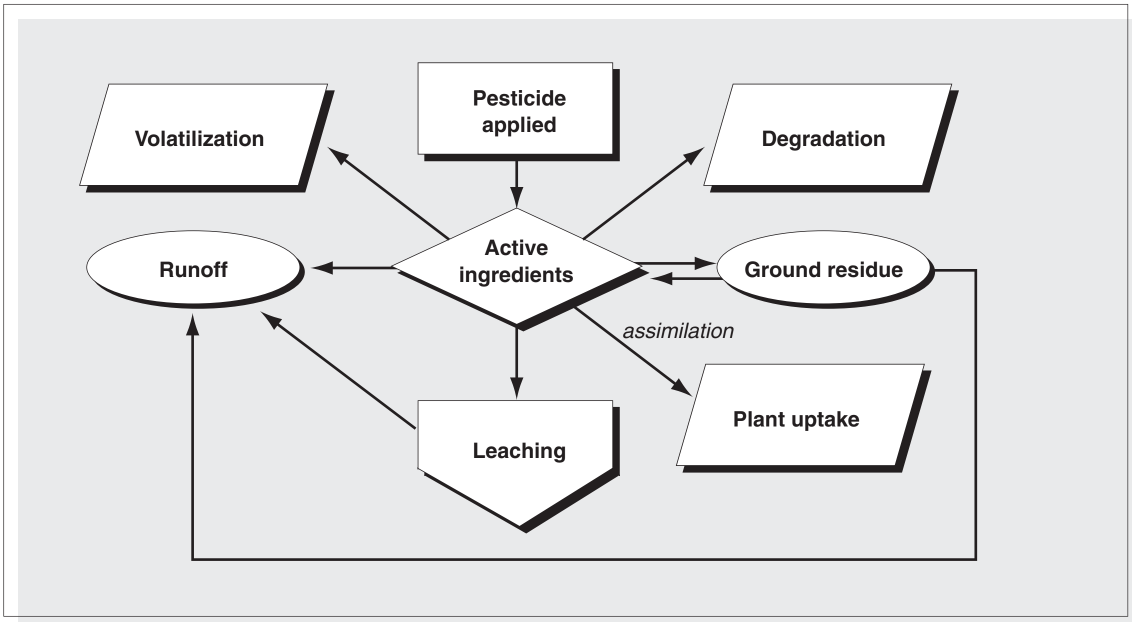
The major sources of pesticides and insecticides include agriculture, combined sewer outfalls, urban runoff, and runoff from rural residential areas. Insecticides include organochlorine, organophosphorus, and carbamate chemicals. Organochlorine compounds, such as DDT, dieldrin, aldrin, heptachlor, and lindane can persist in soils and aquatic environments for many years (Figure 7). For example, DDT has frequently been detected 10 years after its application.

Table 11. Survival of selected pathogens in soils

Organism	Survival time (in days)
Ascaris ova	up to 7
Entamoeba histolytica cysts	6-8
Enteroviruses	8
Hookworm larvae	42
Salmonella	15-100
Salmonella typhi	1-200
Tubercle bacilli	More than 200

Novotny and Olem (1994)

Figure 7. Pathways for pesticide and organic compound transformation and transport



Water quality–related pesticide modeling includes calculations and simulations of pesticide adsorption, decay, and transport. The oxygen status of soils and sediments has a pronounced effect on the microbial breakdown of organochlorine pesticides. In soils and sediments, DDT is rapidly converted to TDE (DDD) under anaerobic conditions. Several organochlorine pesticides, including heptachlor, lindane, and endrin, have been shown to degrade in soils to compounds of lower toxicity and reduced insecticidal activity. Herbicides are less ubiquitous than are organochlorine insecticides. Such compounds as s-triazines, picloram, monouron, and 2,4,5-T often persist in soils for as much as a year following application.

Downward movement of agriculturally applied chemicals into soil layers and groundwater is controlled by soil type, chemistry, pesticide composition, and climatic factors. The leachability of a compound from soils depends primarily on the degree of adsorption of the chemicals on soil particles. Models are also available to evaluate leaching potential (i.e., downward mobility) of organic chemicals. Further information on models to analyze pesticide movement are provided in the "Computer simulations" section.

Toxic metals and organic pollutants

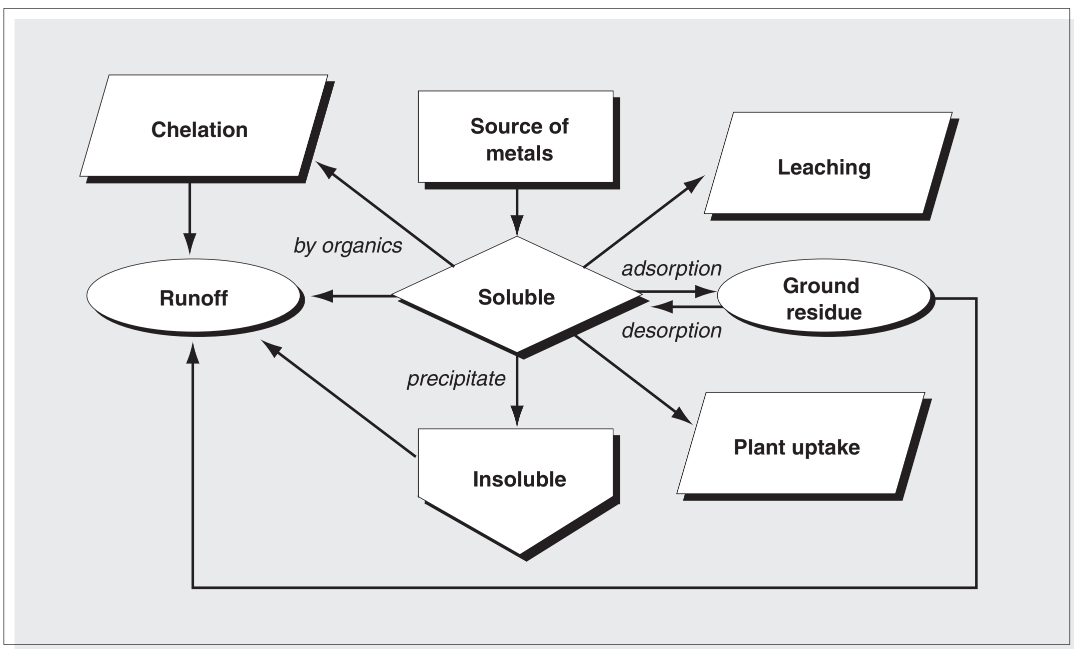
Toxic metals and organic pollutants can be a serious water quality problem within a watershed. While numerous sources exist for these pollutants (Table 12), most of

Table 12. Sources of toxic metals and organic pollutants

Pollutants	Sources
Arsenic	Natural geology, pesticide residue, industrial waste, smelting
Cadmium	Natural geology, mining, smelting
Lead	Lead pipes, lead-based solder
Mercury	Air and water discharge from paint, paper, and vinyl chloride producers, natural geology
Benzene	Petroleum fuel leaks, industrial chemical solvents, pharmaceuticals, pesticides, paints, and plastics
Carbon tetrachloride	Cleaning agents, industrial wastes from coolant manufacturers
p-dichlorobenzene	Insecticides, moth balls, air deodorizers
1,1-dichloroethylene	Plastic, dye, perfume, and paint manufacturers
1,1,1-trichloroethane	Food wrapping and synthetic fiber manufacturers
Trichloroethylene	Pesticide, paint, wax and varnish, paint stripper, and metal degreaser producers, dry cleaning wastes
Trihalomethanes	Surface water containing organic matter treated with chlorine

the toxic substances get into waterbodies and aquifers through point source discharges and stormwater runoff. Modeling the fate and transport of these substances requires knowledge of the chemical and physical characteristics of each particular substance (Figures 7 and 8). Computer simulation software packages are available for such applications.

Figure 8. Pathways for transformation and transport of heavy metals



Computer Simulations

Mathematical models for water quality assessment should be selected based on their intended uses and the conditions specific to the waterbody. A number of water quality models have been developed for general uses. The complexity of these models ranges from relatively simple spreadsheet-based pollutant loading models to extremely intricate, three-dimensional, finite-element models. Historically, many models focused on nutrients, DO, temperature, and BOD problems. Today, however, computer codes capable of handling metals and dissolved constituents are also being introduced. Tables 13 and 14 summarize the main features of several existing watershed simulation models that are generally available to the public. Detailed descriptions of these models can be obtained from other sources (EPA 1997b, Deliman et al. 1999). Tables 13 and 14 are not intended to be comprehensive and do not list models developed by private individuals or companies. Many of these models are proprietary or extremely expensive to purchase.

All water quality models are approximations of mathematical or empirical relationships. Consequently, it is very important that users understand the basic limitations or constraints introduced by the approximations. A great deal of expertise in running and interpreting model results is needed. Models can be shown to produce a widely varying range of outputs depending on the selection of coefficients and other assumptions. Proper calibration, validation, and sensitivity analysis require experience. The validity of the results may be drawn into question by inexperienced modelers. Used properly, models are powerful tools that can be used to help design water quality monitoring programs and evaluate remediation scenarios. However, improperly used models will ultimately lead to inconclusive or erroneous results and may cost more time and resources than they save.

Table 13. Capabilities of water quality models

Models	Source	Attributes							Range of applications			
		Temperature	Nutrients	Metals	Pesticides	Erosion Modeling	Steady-State (SS) or Dynamic (D)	In-stream Water Quality Simulation	Screening	Intermediate	Detailed	Management
AGNPS	USDA	N	Y	N	Y	Y	D	N				
ANSWERS	Purdue	N	Y	N	N	Y	D	N				
BATHTUB	USACE		Y	N	N	N	SS		H	M	-	M
CE-QUAL-RIV1	USACE	Y	Y	N	N	N	D	Y	H	H	H	H
CE-QUAL-W2	USACE	Y	Y	N	N	N	D	Y	L	H	H	H
CE-QUAL-ICM	USACE	Y	Y	Y	Y	N	D	Y	-	M	H	H
CH3D-WES	USACE	Y	N	N	N	N	D	Y	L	M	H	M
CREAMS	USDA		Y		Y	Y		N				
DELFT3D	DELFT	Y	Y	Y	Y	N	D	Y	L	M	H	H
DYNTOX	EPA						D		H	L	-	L
EFDC	Tetra Tech	Y	N	N	N	N	D	Y	L	M	H	M
EUTROMOD	NALMS		Y	N	N	N	SS		H	M	-	M
EXAMSII	EPA	N					SS		H	H	-	M
HSPF	EPA		Y		Y	Y	D	Y	L	M	H	H
PRZM	EPA		N		Y	Y		N				
QUAL2E	EPA	Y	Y	N	N	N	SS	Y	H	H	M	H
SWRRB	USDA		Y		Y	Y		N	M	H	H	M
SMPTOX	EPA	N	N	Y	Y	N	SS	Y	H	M	M	H
TPM	William & Mary	Y	Y	Y	N	N	SS	Y	H	H	M	H
UTM-TOX	ORNL		N		N	Y		N				
WASP5	EPA	N	Y	Y		N	D	Y	L	H	L	H
WEPP	USDA					Y						

H = High N = No
L = Low Y = Yes
M = Medium

EPA (1997b)

Table 14. Overview of water quality models

Watershed-scale loading models

Simple methods	*Mid-range methods*	*Detailed models*
EPA Screening	SITEMAP	STORM
Simple Method	GWLF	ANSWERS
Regression Method	Urban Catchment Model	DR3M-QUAL
SLOSS-PHOSPH	Automated Q-Illudas	SWRRMWQ
Watershed	AGNPS	SWMM
FHA Model	SLAMM	HSPF
Watershed Management Model		
Field-scale loading methods	*Integrated modeling systems*	
CREAM/GLEAMS	PC-VIRGIS	
Opus	WSTT	
WEPP	LWMM	
	GISPLM	
	BASINS	

Receiving water models

Hydrodynamic	*Steady-state water quality*	*Dynamic water quality*	*Mixing zone models*
RIVMOD-H	EPA Screening	DYNTOX	CORMIX
DYNHYD5	EUTROMOD	WASP5	PLUME
EFDC	PHOSMOD	CE-QUAL-RIVI	
CH3D-WES	BATHTUB	CE-QUAL-W2	
	QUAL2E	CE-QUAL-ICM	
	EXAMS II	HSPF	
	TOXMOD		
	SMPTOX3		
	Tidal Prism Model		
	DECAL		

EPA (1997b)

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Form WQ1. Summary of water quality conditions

Sub-basin	Waterbody	Segment	Beneficial uses	Parameters of concern	Indicators of impairment	Notes (data sources, land use hazards)

Historical Conditions

Background and Objectives

Understanding the history and location of natural disturbances (e.g., fires and droughts) and human disturbances (e.g., dam construction and human settlement patterns) provides valuable information about past and current conditions of the watershed. The Historical Conditions module summarizes information on past watershed disturbances and on watershed conditions prior to disturbance.

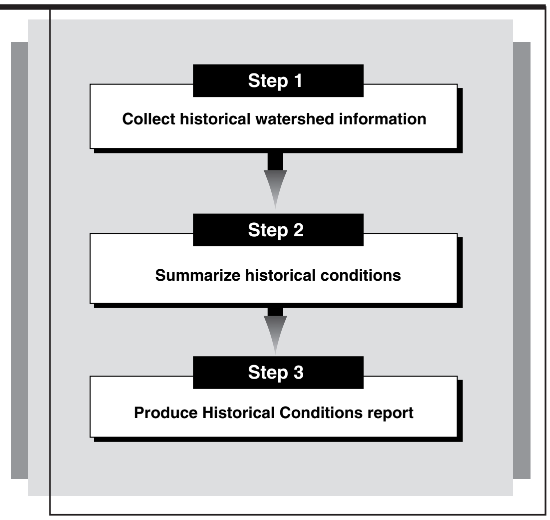
The Level 1 approach relies on existing documents (e.g., maps, surveys, tribal documents, and research papers) as the primary source of historical information. The increased assessment time in the Level 2 approach allows for a more in-depth assessment of historical information or personal interviews with tribal elders and community members. Both the Level 1 and Level 2 approaches summarize the collected information in a timeline, a map, and a historical narrative.

Historical Conditions Module Reference Table

Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
HC1: What land use/management changes have occurred within the watershed since European settlement?	• Historical watershed information: – Land surveys – Settlement patterns – Tribal documents – State and federal reports	• Collect and summarize existing information	• Develop survey/questionnaire • Conduct interviews
HC2: What are the natural setting and disturbance regimes in the watershed?	• Historical watershed information: – Land surveys – Vegetation surveys – Climate data – Fire records	• Collect and summarize existing information	• Develop survey/questionnaire • Conduct interviews
HC3: Where and when have land-scape changes occurred in the watershed?	• Anecdotal information • Historical watershed information: – Land surveys – Vegetation surveys – Fire records	• Collect and summarize existing information	• Conduct interviews

Level 1 Assessment

Step Chart



Data Requirements

- Historical watershed information
- Topographic map of watershed
- Aerial photos

Products

- Form HC1. Historical timeline
- Form HC2. Trends in watershed resource conditions
- Map HC1. Historical sites
- Historical Conditions report

Procedure

The objectives of the Historical Conditions module are as follows:

- To collect historical documents on the settlement and use of the watershed.
- To identify past human and natural disturbances in the watershed.
- To provide a historical context for the use and alteration of watershed resources.

Box 1. Sources of historical information

- Old books and maps
  - Explorers diaries and sketches
  - Historical accounts
- Public land surveys
- Tribal treaties and other documents
- Tribal elders
- Landscape photographs
- Aerial photographs
- City plans
- Local and state history books
- Newspaper accounts
- Scientific journals
- Published oral histories

Step 1. Collect historical watershed information

The first step is to decide where to look for historical watershed information. Box 1 lists possible sources, and Box 2 lists places to start looking for documents on the history of the watershed. Consult the tribal council, tribal elders, and other

Community
Resources
Aquatic Life
Vegetation
Hydrology
Channel

long-time community residents for valuable anecdotal information about watershed conditions and uses. Also, consult with the Community Resources, Aquatic Life, Vegetation, Hydrology, and Channel analysts to share information.

Box 2. Locations of historical information

- Tribal archives
- Historical museums
- City archives
- Local libraries
- State, county, and federal agencies
- Universities and tribal colleges
- Local historical societies

The analyst should gather information about historical development and changes to the landscape (e.g., dam construction, irrigation, settlement patterns, land use). It is also helpful to get information about climatic events and large natural disturbances (e.g., floods, hurricanes, fires, droughts, windstorms, earthquakes, insect outbreaks).

Step 2. Summarize historical conditions

Identify major historical events on timeline

An effective way to summarize historical events is in a timeline format. Figure 1 illustrates a general timeline approach. The detail of the timeline will vary depending on the amount of historical documentation available and the size of the watershed. It may be possible to extrapolate regional information to make assumptions about historical land use and disturbance. Organizing the information as a timeline enables readers to quickly understand the timing of important events that have affected watershed conditions. Whatever format is used for the timeline, label it Form HC1.

Figure 1. Sample Form HC1. Historical timeline

Date	Historical Event
1850s	First eastern brook and rainbow trout stocked in Kootenai
1890s	Early attempts at dike construction
1890s-1930s	Channel alteration from log drives in tributaries
1910	Wildfires
1925	Lake Creek Dam in operation
1930	Moyie Dam in operation
1940	Sturgeon declines, commercial fishing stopped
1950-1970	Cominco Fertilizer Plant
1980	Non-selective kill from gas bubble disease, 17 miles from dam

Adapted from Sasich et al. (1999)

Summarize trends in resource conditions

From the information presented in the timeline, trends in resource conditions may be identified, and connections between land use practices and resource trends can be hypothesized. From the Kootenai timeline (Figure 1), trends in resource conditions can be connected to specific land use practices, such as dike construction, log drives, and dam operation. Information on watershed changes can be listed in Form HC2 (Figure 2). Consult with the Community Resources, Aquatic Life, and Water Quality analysts for a complete list of resources.

Community Resources
Aquatic Life
Water Quality

Figure 2. Sample Form HC2. Trends in watershed resource conditions

Resource	Trend	Disturbance
Sturgeon	• Declining numbers found in Kootenai and tributaries	• Channel alteration • Impacts from dams
Wetland habitat	• Decreasing numbers of wetlands	• Dike construction
Water quality	• Higher quantities of chemicals in water	• Dam operations • Industrial effluent • Mines

Adapted from Sasich et al. (1999)

Write watershed historical narrative

The watershed historical narrative pulls together the information collected on historical watershed conditions and natural and human disturbances. Beginning from the earliest information available, tie together the history of water quality, aquatic life, land use impacts, channel alterations, and settlement patterns. A sample watershed historical narrative is provided in Box 3.

Map historical sites and landscape disturbances

Once the historical information is summarized, it may be useful to map the locations of historical sites and disturbances (Map HC1). If the watershed is large, break it into sub-basins to get a finer resolution.

Box 3. Watershed historical narrative from Quinault Watershed Analysis

The Upper Quinault River Valley remained geographically isolated until exploration by the Gillman Expedition in 1889. The first Euroamerican settlers arrived in the Cook/Elk and Quinault Lake [areas] in 1889, and practiced subsistence farming and grazing. By 1897, homesteaders had occupied most of the suitable bottom lands around Lake Quinault and as far upstream as the confluence of the North and East Forks of the Quinault River. Present day settlement is concentrated in the Neilton and Amanda park areas near Quinault Lake and in the unincorporated village of Taholah, located at the mouth of the Quinault River.

Timber harvesting, fishing and tourism have been the prominent economic influences in the Quinault River watershed. Logging began in 1916, when cedar was salvaged from the "Neilton Burn". By 1924 the advent of railroad logging made large-scale commercial timber harvesting viable in the Cook/Elk and Quinault River [areas]. Extensive road construction and subsequent timber harvesting occurred between 1950 and 1980. Although the level of old growth harvesting has declined in recent years, second growth forest management and related forestry activities such as cedar salvage and gathering of special forest products will continue to play an important role in the local and regional economy.

Quinault Indian Nation (1999)

Types of information to be placed on Map HC1 include the following:

- Dams and diversions.
- Water quality impacts (e.g., toxic spill, algal bloom).
- Channel modifications (e.g., dikes, channel straightening).
- Historical fishing sites.
- Historical wetlands and floodplains.
- Historical sites.
- Fires.

Step 3. Produce Historical Conditions report

The Historical Conditions report should include the watershed historical narrative, the map of historical sites (Map HC1), and the forms showing a historical timeline and resource trends (Forms HC1 and HC2). A possible outline for the report is provided in Box 4.

Box 4. Sample outline for Historical Conditions report

A. Historical Watershed Narrative

1. Watershed resources at time of European settlement
    - a. Native American use
    - b. Vegetation
    - c. Presence and abundance of fish and wildlife species
    - d. Stream habitat
    - e. Natural disturbance patterns
2. Historical settlement, land use, and resource management patterns
    - a. Settlement patterns and development: rural and urban
    - b. Roads
    - c. Dikes
    - d. Logging practices
    - e. Agriculture
    - f. Urbanization
    - g. Grazing
    - h. Mining
    - i. Water use, diversions
    - j. Fisheries exploitation
    - k. Changes in disturbance patterns

B. Summaries of Historical Conditions

1. Form HC1. Historical timeline
2. Form HC2. Trends in watershed resource conditions
3. Map HC1. Historical sites

C. Conclusions

1. Summary of watershed conditions and change
2. Conclusions about historical conditions that are currently impacting community resources

D. Sources of information

Adapted from Watershed Professionals Network (1999)

Level 2 Assessment

The Level 2 assessment is similar to the Level 1 assessment, but more time and resources may allow for more extensive information collecting activities, such as the following:

- Sending out a questionnaire to community members.
- Conducting personal interviews.
- Working with a local historian or university anthropology department.

References

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Form HC1. Historical timeline

Date	Historical Event

Form HC2. Trends in watershed resource conditions

Resource	Trend	Disturbance

Hydrology

Background and Objectives

The purpose of the Hydrology module is to characterize the hydrologic regime of the watershed and assess its susceptibility to alterations from land and water use practices. When hydrologic processes are altered, the stream system responds by changing physical parameters, such as channel configuration. These changes may in turn impact chemical parameters and ultimately the aquatic ecosystem.

The degree to which hydrologic processes are affected by land and water use depends on the location, extent, timing, and type of activity. Watershed activities can potentially cause changes in the magnitude and timing of both peak flows and low flows. Some activities (e.g., temporary roads, low levels of timber harvest, and seasonal irrigation withdrawals) cause short-lived alterations to the hydrologic regime, while other activities (e.g., dams, urbanization, and channelization) cause fairly permanent changes in the watershed and thus to the hydrologic regime.

Hydrologic processes are complex, involving myriad interactions that are difficult to quantify. The list of hydrologic concerns generated in the Scoping process will provide direction to the assessment. In addition, seven critical questions are posed to help focus the assessment. The Hydrology Module Reference Table indicates the critical questions that may be addressed in the initial Level 1 assessment and options for further Level 2 analyses. This module provides detailed steps for Level 1 assessment and a general discussion of options for Level 2 assessment.

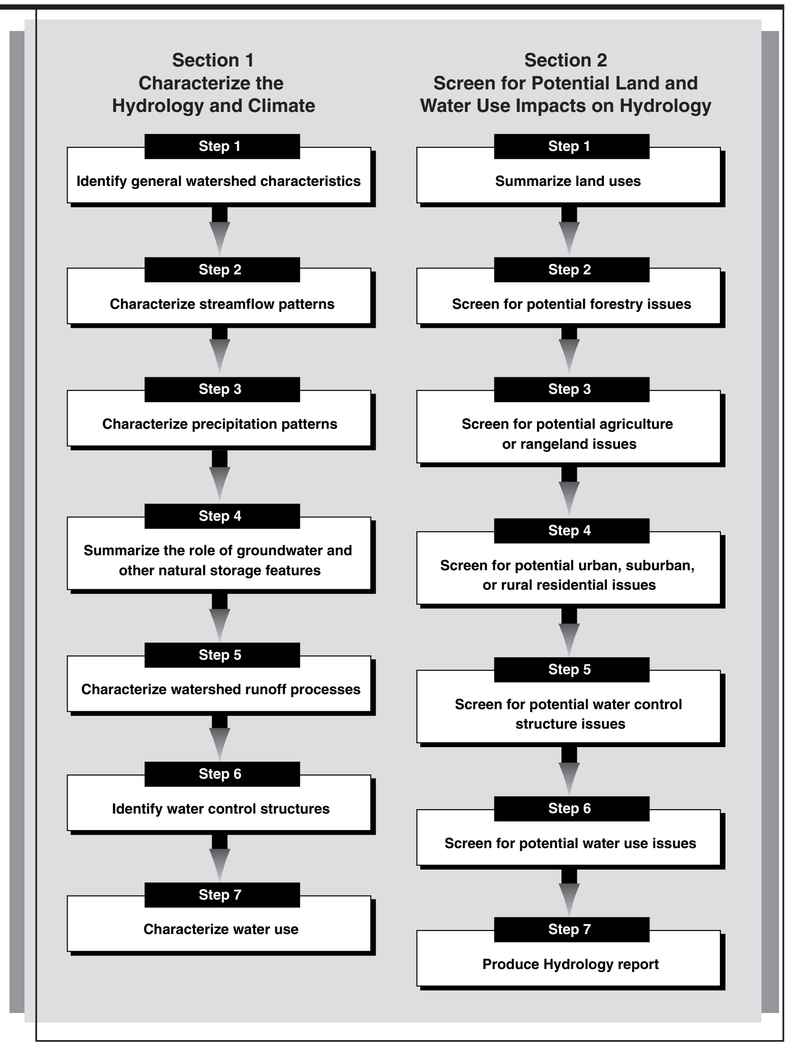
Level 1 assessment characterizes the hydrology and climate of the watershed and screens for potential land and water use impacts. Characterization refers to gathering and organizing existing data into a qualitative description of conditions. The Level 1 assessment does not produce definitive or quantitative results; however, the screening does provide justification and focus for future Level 2 assessment.

Hydrology Module Reference Table

Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
H1: What is the seasonal variability in streamflow?	• Representative streamflow records	• Tabulate and graph flow data • Summarize peak and low flow patterns	• Ungaged streamflow analysis • Frequency analysis (flood and low flow) • Flow duration curves
H2: What is the climatic setting of the watershed?	• Representative climate data • Topographic maps • Watershed characteristics	• Tabulate and graph precipitation data • Summarize storm patterns	• Storm analysis • Trend analysis • Double mass analysis
H3: What are the roles of groundwater and natural storage features in the watershed?	• Hydrogeologic maps and aquifer descriptions • Vegetation module maps	• Locate storage features in the watershed: snowpack, lakes, wetlands/swamps • Define groundwater areas	• Hydrograph separation techniques • Characterize surficial aquifers
H4: What are the active runoff generating processes?	• Topographic maps • Watershed characteristics	• Describe runoff processes	• Storm analysis • Watershed hydrologic models
H5: What water control structures are present in the watershed?	• Historical Conditions module timeline • Aerial photos • Topographic maps	• Locate reservoirs, lakes, diversions, dams • Characterize extent of draining and ditching and other hydromodifications	• Deregulate streamflow records • Reservoir routing models • Reservoir operation models • Watershed hydrologic models
H6: For which beneficial uses is water primarily used in the watershed, and are surface water or groundwater withdrawals prominent?	• Land use map • Topographic maps • Aerial photos	• Identify types of water uses and typical withdrawals in the watershed • Determine periods of high water demand	• Water rights analysis • Consumptive use estimates • Water balance calculations • Network/allocation models • 3D groundwater models
H7: What are the potential land use impacts to hydrologic processes in the watershed?	• Percentage of watershed occupied by each land use • Vegetation coverage • Hydrologic soil information • Percentage impervious area	• Screen for potential impacts	• Empirical relationships • Regional relationships and models • Storm hydrograph techniques • Continuous hydrologic models

Level 1 Assessment

Step Chart



Data Requirements

- Map of the watershed showing topography and stream network. USGS or equivalent topographic quadrangle maps at a 1:24,000 scale are adequate.
- Stream network classification map (if available). Many states have adopted regulatory categorizations pertinent to stream order (e.g., stream order, water type, stream class). If state classification maps are available, they can be useful to cross-reference with the Channel module and Aquatic Life module analysts.
- Land use map with sub-basins delineated (from Scoping).
- Mean annual precipitation map.
- USGS hydrologic atlases and groundwater atlases.
- Streamflow data.
- Soil survey maps.
- Surficial geology maps (if available).
- Hydrogeologic maps describing aquifer conditions (if available).
- Aerial photos or orthophotos (as necessary).
- Other relevant published or unpublished documents (city, county, tribal, state, or federal agency or private consultant reports) with watershed information.

Data Sources

The USGS is the best source of water-related information in the United States. The USGS collects streamflow, surface water quality, groundwater level, and groundwater quality data. It publishes water resources data by state and water year, water resources investigation reports, open-file reports, water resources bulletins, professional papers, and hydrologic investigations atlases. USGS publications are available in many libraries or they can be ordered through the U.S. Government Printing Office. The information number for the USGS is **1-800-426-9000.**

Hydrologic data

Current and historical streamflow data can be downloaded from the home pages of the USGS district water resource offices. Streamflow data are also available commercially on CD-ROM. Published resources include the following:

- USGS. *National Water Summaries: Hydrologic Events and Surface-Water Resources*. These documents contain nationwide and state information on water resources, including generalized maps of surface water runoff, water-related issues, groundwater quantity and quality, and wetland locations.
- U.S. Water Resources Council (1978). *The Nation's Water Resources*. Although dated, this is still the most recent and comprehensive nationwide assessment of the United States' water problems.
- USGS publishes open file reports containing regional flood equations (e.g., USGS 1979).

Climatic data

The National Weather Service and its data repository, the National Climate Data Center, have websites that provide easy access to useful climate information (**http://www.nws.noaa.gov** and **http://www.ncdc.noaa.gov**). Climate data are also available commercially on CD-ROM. There are six regional climate centers (Western Regional, High Plains, Southern, Midwestern, Southeast, and Northeast), each of which can provide information on how and where to download climate data and assist in identifying an appropriate climate station. Some states have designated state climatologists who are a valuable resource. Published resources include the following:

- NOAA National Weather Service. The Climatic Record of the United States by State. These documents contain daily, monthly, and annual climate information on precipitation, temperature, evaporation, degree days, and other climate data by weather station. NOAA also publishes a *Mean Annual Precipitation Map*.

- U.S. Weather Bureau Technical Paper 40, *Rainfall Frequency Atlas of the United States* provides information on 24-hour storms for the conterminous United States. Precipitation atlases for specific states (e.g., Miller et al. 1973) are also available.

Water use data

The USGS updates water use estimates every five years. Water use data can be obtained through the USGS water use icon on the EPA's Surf Your Watershed web site (**http://www.epa.gov/surf/**).

Groundwater resources data

- Hydrogeologic provinces. Heath (1984).
- *The Ground Water Atlas of the United States*, USGS Hydrologic Investigations Atlas, HA 730 A-N series. This atlas consists of 14 chapters that describe the groundwater resources of regional areas. A nationwide aquifer map is included along with descriptions of groundwater characteristics, flow directions, chemical composition, and water balance components such as runoff, precipitation, and evaporation. The text of this atlas is available online (**http://wwwcapp.er.usgs.gov/publicsdocs/gwa**).

Products

- Form H1. General watershed characteristics
- Form H2. Summary of hydrologic issues by sub-basin
- Map H1. Water control structures
- Hydrology report

Procedure

The primary objectives of the Hydrology assessment are as follows:

- To characterize the hydrologic regime of the watershed by summarizing the following:

– Watershed characteristics.
– Streamflow patterns.
– Precipitation patterns.
– Watershed storage and groundwater features.
– Watershed runoff processes.

- To locate land uses (agriculture and rangeland, urban, forestry, mining, etc.), water uses, and water control structures (dams, dikes, diversion, etc.) in the watershed.
- To screen for potential impacts on hydrology from land and water use.

The Level 1 evaluation procedure is separated into two sections. The steps in Section 1 characterize the hydrologic and climatic setting of the watershed. The steps in Section 2 direct the user to screen for potential hydrologic issues associated with the land and water uses present in the watershed.

The hydrologic evaluation may need to be carried out at the sub-basin level. This will require adjusting streamflow and precipitation records to reflect conditions in each sub-basin.

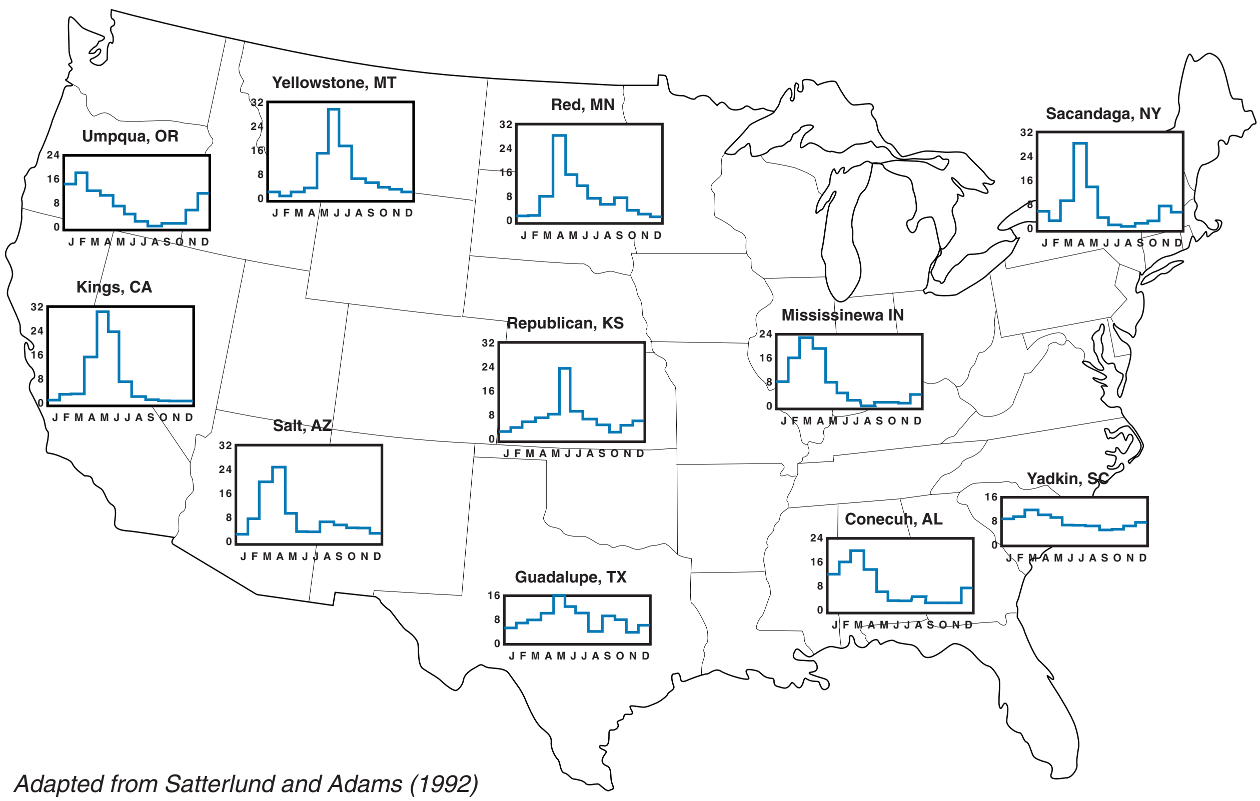
Section 1. Characterize the Hydrology and Climate

The geographic layout of the United States encompasses several diverse physiographic and climatic zones, causing the amount of runoff and its distribution throughout the year to vary considerably from region to region (Figure 1). Watersheds differ in both the ability to produce flood flows and the ability to sustain flows during the dry periods.

Most streams do not produce uniform flow over the year. Instead, streams typically exhibit patterns in flow reflective of individual storms, months, and seasons (Figure 1). The seasonal pattern of streamflow in a watershed is largely governed by the climatic inputs to that watershed (the amount, form, and timing of precipitation) offset by losses from the watershed (the amount and timing of evapotranspiration losses and snowmelt). The geologic characteristics of the watershed also heavily influence the streamflow regime, as demonstrated by the marked difference between the hydrographs compared in Figure 2. (A graphical plot of streamflow data over time is called a hydrograph.) Finally, physical characteristics—such as the size of a river system, drainage shape, topography, type of vegetation or ground cover, and amount of natural water storage—all influence the specific runoff pattern of a given stream.

While flooding is common in each of the 50 states, the type and frequency of peak flow events differ dramatically both within and among states. Floods can stem from many factors, including heavy rainfall, rapid snowmelt, rain-on-snow, and thunderstorms, as well as more dramatic ice jam breakups, channel avulsions, and dam or levee failures. In coastal areas, hurricanes, winter storms, tsunamis, and rising sea levels can generate floods.

Figure 1. Average monthly runoff (as a percentage of annual flow) for selected gages in the United States

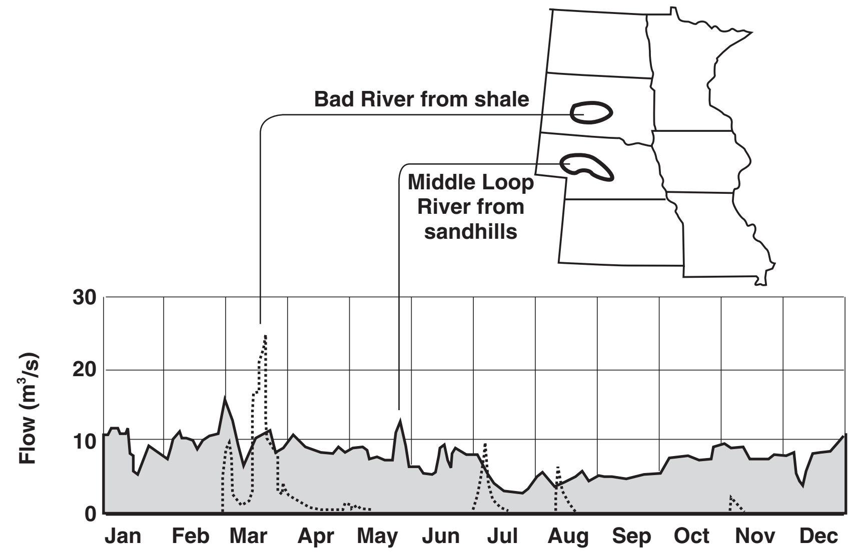


Adapted from Satterlund and Adams (1992)

Baseflows or low flow regimes also vary from stream to stream. Intermittent streams go dry for a period of time every year, while other streams do not experience much fluctuation from high flow to low flow periods (see example for Yadkin, South Carolina, in Figure 1). Many factors influence the amount of water found in streams during the low flow period:

- Rate of snowmelt and glacial melt.
- Geologic characteristics.
- Outflow from lakes and reservoirs.
- Rate of evapotranspiration from soils and vegetation.
- Effects of upstream water withdrawals and irrigation return flows.

Figure 2. Geology modifies streamflow regime from two watersheds with similar climates



Adapted from Satterlund and Adams (1992)

Several of the influencing factors may only be important in certain regions. For instance, assessing the importance of glacial melt in sustaining late summer/early fall low flows will be required for some watersheds located along the Pacific Northwest's Cascade Mountain range and in Alaska, as well as a few watersheds in the Northern Rocky Mountain and Canadian Rocky Mountain ranges. Wetlands, while present throughout the nation, are most prevalent along the southern seaboard, gulf coast, and lower Mississippi River and in the glacial terrain of the north-central United States.

Each region and even each watershed will have unique issues. This section will focus on summarizing physical watershed characteristics and collecting available streamflow and climate data in order to discern the hydrologic issues. The typical distribution of runoff over the course of the year as well as the dominant peak flow and low flow issues in the watershed will be investigated.

Step 1. Identify general watershed characteristics

Using the watershed base map generated in the Scoping process, review and clearly delineate the boundaries of each identified sub-basin. Form H1 can be used to compile and organize watershed-specific hydrologic information. For each sub-basin, identify basic watershed features such as drainage area, topographic relief (e.g., minimum and maximum elevations), geology, drainage pattern, stream gradient, and mean annual precipitation. If GIS support is available, some of the information can be calculated using the computer. Otherwise, use USGS topographic maps and a map of mean annual precipitation (from NOAA or a state agency) to estimate values for each characteristic.

Step 2. Characterize streamflow patterns

Identify gages

Identify any streamflow gages in or near the watershed of interest and develop a table summarizing station information such as the station name, location, elevation, and period of record.

The USGS has been operating streamflow stations across the country since the turn of the century. In some regions, stream gages are numerous and have long periods of record, while in other regions (e.g., west of the Mississippi), there are fewer gages and they have shorter periods of record. The following are factors to consider in finding representative streamflow data:

- Where gages are numerous, the task will be to select the most useable and representative gages.
- Watershed size will be an important decision criterion, as will length of record; longer records offer more insight into the variability of streamflow. To obtain representative data for a watershed, the gage records should cover at least ten years.
- The gaging station does not need to be currently in operation; historical data still offer a glimpse into how a watershed responds to storm inputs (precipitation, temperature, wind, etc.).
- Gage records should represent unregulated streamflow (where no reservoirs or diversions exist above the gaging station). Gages downstream of a reservoir or even a millpond will not record natural peak flows but will reflect streamflow modified by the structure (Box 1).

Box 1. Regulated watersheds

For watersheds with dams, large-scale diversions, or other flow-altering activities; streamflow data remarks will need to be reviewed in detail prior to use. The first task will be to determine the unregulated portion of the record, prior to completion of the flow-altering activity. Summary statistics and hydrographs developed from the unregulated portion of the streamflow record can offer an indication of the pre-alteration flow regimes. Techniques for deregulating the post-alteration record can be undertaken as a Level 2 analysis.

The USGS information office nearest the watershed can help locate an appropriate gage or gages. If a stream gage is not located in the watershed, obtain records for a nearby stream gage draining a hydrologically similar watershed. Gages located in adjacent watersheds will not necessarily be representative of conditions in the watershed being assessed. Therefore, it is important to assess hydrologic similarity by using the basic criteria listed in Box 2 prior to selecting a surrogate gage. When hydrologic similarity criteria are not met, ungaged streamflow analysis may need to be conducted (Box 3).

Box 2. Criteria for assessing hydrologic similarity of two watersheds

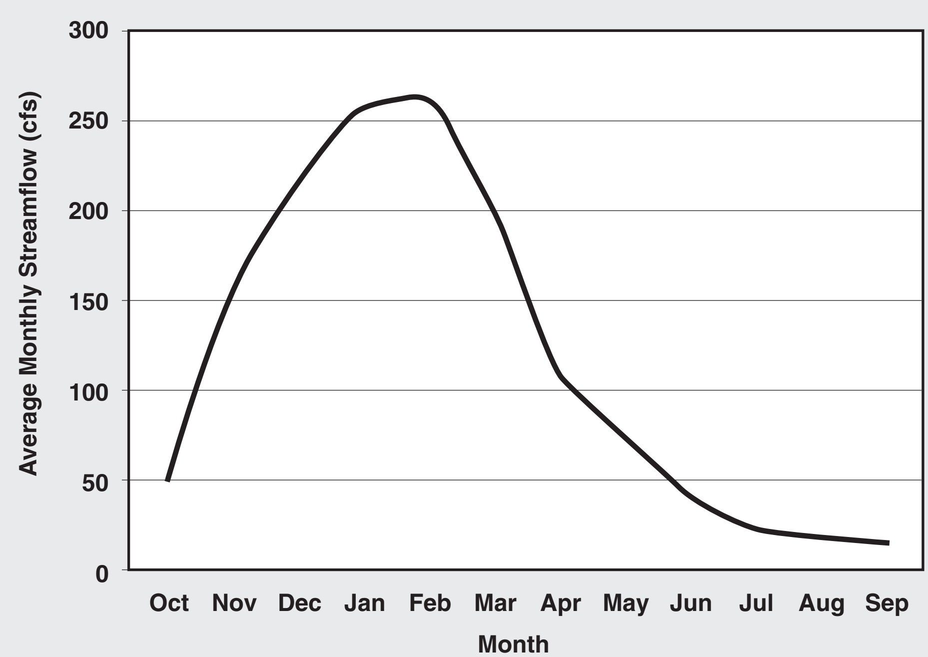
- Watershed drainage areas within the same order of magnitude
- Similar mean watershed elevation above the gage
- Similar precipitation and weather patterns
- Similar geology and topography
- No or insignificant out-of-stream diversions

Robison (1991)

Generate hydrographs

Obtain the mean monthly streamflow for the period of record for each of the selected streamflow stations. Generate a typical annual hydrograph (Figure 3) for each station. The shape of the hydrograph provides an identifying characteristic of a watershed. If more than one

Figure 3. A typical annual hydrograph for winter storm-driven regime



Box 3. Estimating streamflow in ungaged watersheds

For watersheds where either no or minimal streamflow data are available, numerous methods exist to estimate streamflow. Only the methods that do not require extensive data or modeling are presented here.

Flood regression equations

The USGS has developed regional flood regression equations for many areas of the United States. These reports are typically published by state and entitled Magnitude and Frequency of Floods. The equations can be used to estimate different flood events, such as the 2-year flood, 25-year flood, etc., based on watershed area, precipitation, and land cover. Inquire at the nearest USGS office about appropriate regional equations.

Area-precipitation method

In humid areas of similar geology, mean annual flow is closely related to drainage area and mean annual precipitation. Mean flows may be estimated if 1) flow records from nearby watersheds are available; 2) an isohyetal map is available (isohyets are contour lines of equal precipitation); and 3) the geology of the area is relatively homogeneous.

Unit runoff method

Streamflow from a hydrologically similar watershed can be converted into runoff per unit area (e.g., cubic feet per square mile) to estimate some of the streamflow statistics for the ungaged watershed. Please note that these statistics are general estimates to be used to assess relative magnitudes rather than absolute values. If there are any miscellaneous streamflow measurements made in the watershed, these data can be compared to a gaged station to establish a predictive relationship (i.e., regression analysis).

Surface water runoff maps

Use the USGS generalized maps of surface water runoff.

stream gaging station exists in the watershed, compare the hydrographs from each. Consider the following questions:

- In which month or months does the majority of runoff occur?
- When do low flows occur?
- If comparing hydrographs, do they generally have the same shape, or does the timing of runoff vary?
- Are flow patterns seasonally predictive?
- Do streams show great fluctuations in flow within seasons?

Optional Task: Where representative daily streamflow data are available, develop the average daily hydrograph using the entire period of record. Compare daily flows over a few years.

Aquatic Life

Flow variability is an important factor to aquatic ecosystems. The information collected in this step may be useful to the Aquatic Life analyst. For example, the hydrographs can be compared to the aquatic species' stream flow requirements to illustrate the timing of streamflow in relation to the needs of aquatic life.

Summarize peak flow data

Obtain and graph the annual peak flow data associated with the selected streamflow gages (Box 4). Enter the data into a table (similar to Figure 4) that tracks the magnitude of annual peak flows in cubic feet per second (cfs) and the date of each peak flow. Consider the following questions:

Aquatic Life

- In which month or months do the majority of the annual peak flows occur?
- Do extreme high flows occur during critical periods for aquatic life?
- Have high flows influenced habitat conditions?

Box 4. Annual peak flows and water years

For each station, a record of annual peak flows should be available (see the "Data Sources" section). Annual peak flows represent the highest recorded discharge for that station for a given water year. The water year differs slightly from the calendar year. Water year is defined as the 12-month period starting on October 1 and ending on September 30. October 1, 1999, through September 30, 2000, would be referred to as water year 2000.

Summarize minimum flow data

Obtain and graph the annual minimum flow data associated with the selected streamflow gages. These data are available from numerous data sources. For instance, the USGS Water Resources Data series, published by state for each water year, provides summary statistics for each station currently in operation. Among the statistics, lowest mean daily flow can be found along with the annual seven-day minimum (lowest mean streamflow for seven consecutive days in a water year; see also Box 5). Report the magnitude of low flows and their dates of occurrence in a table similar to the

Box 5. Low flow frequency

Low flow statistics often include reference to the seven-day ten-year low flow ($7Q_{10}$). The $7Q_{10}$ is a statistic that represents the lowest mean discharge for seven consecutive days that has a probability of occurring once in ten years.

Figure 4. Sample table format for summarizing annual peak flow data

Annual peak flows for each water year of record

Station name: Station number:

Drainage area: Period of record:

Water year *	Peak flow amount (cfs)	Date of peak flow	Season of peak flow

** October 1 - September 30*

peak flow data table (Figure 4). In addition, record the minimum discharge for the period of record of the gage. Consider the following questions:

- In which month or months do the annual minimum flows typically occur?
- Do extreme low flows occur during critical periods for aquatic life?

Aquatic Life ▶

Step 3. Characterize precipitation patterns

Collect precipitation information

Obtain the NOAA mean annual precipitation map. Identify the climate stations nearest to your watershed and develop a table summarizing station information, such as station name, location, elevation, and period of record.

Summarize precipitation information

Describe the range and variability of precipitation from the mouth to the headwaters of the watershed and among the sub-basins. In addition, obtain the average monthly precipitation for the period of record and graph the annual distribution of precipitation. This graph of the rate of rainfall over time is called a hyetograph. Obtain and graph the annual maximum 24-hour precipitation. Consider the following questions:

- In which month or months does the majority of precipitation occur?
- When are the dry seasons?

- In which month and year does the largest annual maximum 24-hour precipitation event occur?
- Is this the same storm that produced one of the largest peak flows?
- In what month do most of the maximum 24-hour precipitation events occur?

Examine trends in data
If the period of record for the streamflow station and climate station overlap, examine the pattern that has occurred for peak flows and precipitation over time. Consider the following questions:

- Are annual peak flows consistently increasing or decreasing over a period of the record?
- Does a cyclical wet and dry pattern emerge in which short periods of lower peaks are interspersed with periods of higher peaks?

Historical Conditions

If some pattern seems apparent, then the next step is to discern whether the pattern mimics the climatic pattern. If there is a trend in the peak flow graph that is not apparent in the precipitation graph, then further study may be warranted. Keep this point in mind when proceeding with the hydrologic screening tasks. Note the year in which the trend in peak flows becomes apparent and the year in which it stops and try to identify major watershed changes that might have occurred coincidentally. Also be sure to review the streamflow and climate station histories to check for changes in gage locations. Check the Historical Conditions module timeline for input on watershed changes.

Step 4. Summarize the role of groundwater and other natural water storage features

Natural water storage features play a role in the runoff response of the watershed. In fact, hydrologic regimes in some regions are dominated by their storage components. "Storage-based"systems or subsurface-dominated flow regimes typically release water slowly over long periods of time. For instance, in the pine flatwoods of Florida, surface runoff occurs only when the groundwater table intersects the soil surface. Conversely, most rangelands, absent dense vegetation, offer little water storage. Surface runoff is the most common form of conveyance as evidenced by numerous rills and ephemeral channels.

Almost all streams interact with groundwater to some extent. In fact, groundwater discharge to streams (termed baseflow) often accounts for 50 percent or more of the average annual streamflow. The proportion of stream water that is derived from groundwater inflow, however, can vary considerably across physiographic and climatic settings. Streams can interact with groundwater in one of three ways:

1. Streams gain surface water from groundwater inflow.
2. Streams lose water to groundwater by outflow through the streambed.
3. Streams do both, gaining at some times or in some reaches and losing at other times or in other reaches.

Groundwater boundaries in many instances do not coincide with watershed boundaries; groundwater/surface water interactions are largely controlled by the geologic setting (Box 6). As an example of the effect that geology can have on the groundwater contribution to streamflow, Winter et al. (1999) compared the Forest River watershed in North Dakota with the Sturgeon River watershed in Michigan. The Forest River watershed is underlain by poorly permeable silt and clay deposits, which limit the contributions of groundwater to streamflow to around 14 percent of average annual flow. By contrast, the Sturgeon River watershed is dominated by highly permeable sands and gravels, causing the groundwater component of streamflow to be large, approximately 90 percent of its average annual flow.

Erosion

Box 6. Hydrologically closed systems

Watersheds located in the glacial and dune terrain (the prairie-pothole region) of the north-central United States are characterized by hills and depressions with many lakes and wetlands. While streams drain portions of this terrain, typically they do not form a large drainage network, and stream outlets are often absent, indicating a "closed" system. Movement of water through this terrain is controlled primarily by exchange of water with the atmosphere (through precipitation and evapotranspiration) and with the ground water.

Antecedent precipitation conditions also influence groundwater/streamflow interactions. During storms, a rising water level in the stream channel typically reverses the direction of groundwater flow, causing storage of water in the floodplain and recharge of adjacent aquifers. As the stream recedes, the stored groundwater is released slowly back to the stream.

Vegetation

Inventory water storage features

Locate and describe surficial water storage features in the watershed such as lakes, ponds, wetlands, and swamps. In some regions, the USGS has compiled descriptive watershed information for each streamflow gaging station (Williams et al. 1985). The EPA Surf

Your Watershed web page (**http://www.epa.gov/surf/**) has information on the number of lakes in the watershed, as well as the name, description of rock types, and square miles of coverage for each underlying aquifer. Confer with the Vegetation analyst to obtain the vegetation map documenting the extent of wetlands identified on the NWI maps and through aerial photo interpretation. If information is not readily available, storage features can be identified on topographic maps and aerial photographs.

Summarize snow data

If snow accumulates in the watershed, identify snow data collection stations in or near the watershed. The NRCS collects snowpack depth and snow-water equivalent data at stations in many regions. Contact the local NRCS office to determine whether snow stations are actively monitored in or near the watershed. Also, check with the USFS for snow data. Determine in which sub-basins snow accumulates and, if possible, estimate the snow pack depth.

Identify the presence of glaciers in the watershed. Glacial streams, primarily during low flows, will exhibit characteristics different from those for neighboring streams that are fed by snowmelt, lakes, and groundwater.

Summarize groundwater resources

Use available hydrogeologic resources, such as existing reports, maps, and aquifer descriptions, to summarize the knowledge of groundwater issues by sub-basin. The USGS Groundwater Atlas provides aquifer descriptions for most regions. Locate areas of productive groundwater discharge in the watershed (e.g., well fields, springs) and also potential areas of groundwater recharge (e.g., karst terrain; Box 7).

Over the past decade, as the joint management of groundwater and surface water resources has come to center stage, investigators have focused on characterizing the interactions. If the watershed is in an area with a recently completed regional-scale

Box 7. Karst terrain

Karst terrain refers to areas of highly disrupted surface water drainage systems due to the dissolution of underlying bedrock (typically limestone and dolomite). Solution openings, rock openings, and sinkholes intersect the surface, providing connection to the underground drainage network. Precipitation onto areas where karst terrain outcrops at the land surface tends to infiltrate quickly. Even large streams can run dry as they recharge the groundwater directly through sinkholes and solution cavities. This direct link also leaves groundwater resources very susceptible to pollution.

USGS studies (Brown and Patton 1995) found that streams traversing the karst terrain associated with the Edwards Aquifer in south-central Texas can lose considerable amounts of water. Yet, karst aquifers can also produce ample groundwater discharge. For example, springs near the margin of the Edwards Aquifer provide a continuous source of water for streams to the south.

North-central Florida provides an example of a mantled karst region with numerous sinkhole lakes. Many lakes in this region form as unconsolidated surficial deposits slump into sinkholes in the underlying highly soluble limestone of the Upper Floridian Aquifer.

baseflow study (Box 8), use the report to help define the role that groundwater plays in maintaining the streamflow.

Box 8. Baseflow studies

Recently completed baseflow studies are available for several regions in the country:

- Washington State, selected rivers and streams (Sinclair and Pitz 1999).
- The Great Lake area (Holtschlag and Nicolas 1998).
- The Chesapeake Bay area (Bachman 1997; Langland et al. 1995).
- The Appalachia region (Rutledge and Mesko 1996).
- The Central Savannah River watershed (Atkins et al. 1996).
- Pennsylvania (White and Sloto 1990).
- Tennessee (Hoos 1990).

Step 5. Characterize watershed runoff processes

The purpose of this step is to identify the relative importance of the runoff pathways (surface and subsurface) within the watershed. Using the information gathered in Steps 2 through 4, summarize the interaction among streamflow, precipitation inputs, groundwater, and storage components. Discuss, to the extent possible, the mechanisms by which runoff is generated. More than one runoff process can be active in a watershed, and often a predictable pattern will emerge (Box 9).

Box 9. Example runoff descriptions

- In forested watersheds draining deep soils in the Sierra Nevada Mountains, winter snow accumulation and spring snowmelt are the primary influences on the shape of the annual hydrograph. However, other hydrologic processes are also active. Groundwater release sustains streamflow relatively well into the summer, and all the more extreme peak flow events have resulted from mid-winter rain-on-snow events. Rain-on-snow events have typically generated peak flows up to five times greater than spring snowmelt peak flows.

- Some watersheds in the unvegetated shallow cirques of the Sierra Nevada Mountain alpine zone are snowmelt-dominated. Groundwater may contribute only a small portion of the total annual amounts of surface water; however, the groundwater inputs are the primary source of water for 8 to 9 months of the year.

As a general rule, overland flow pathways are dominant in arid areas and on paved urban areas or disturbed landscapes where infiltration capacity is often limited. Subsurface flow is more prevalent in humid regions with dense vegetation and deep, permeable soils. Where subsurface flow is a dominant contributor to storm runoff, the percentage of precipitation that reaches the stream during the storm is low; most of the rain is stored in the soil and groundwater, then released slowly.

Further distinction can be made regarding the influence of climate on runoff. In rainfall– or rain-on-snow–dominated hydrologic regimes, annual maximum precipitation events often occur at the same time of year as the annual peak flows. By contrast, in areas with a snowmelt-dominated regime, maximum precipitation events do not yield the largest floods; instead, spring melting of the accumulated winter precipitation (stored in the snowpack) generates peak flows. Watersheds with extensive wetland systems and other forms of storage will also show streamflow desynchronized from the precipitation inputs. In arid regions, intermittent streams often yield flash floods in response to high intensity rainstorms. The intensity of rainfall in these areas can be a more important factor in determining runoff than the total amount of rainfall. In the Great Plains region, thunderstorms provide more than half of the precipitation during the growing season (Maidment 1992).

Step 6. Identify water control structures

Locate on a map the water control structures in the watershed. Man-made structures and storage facilities such as water supply reservoirs, flood control reservoirs, and even abandoned dams (millponds) impact the streamflow downstream of the impoundment (Box 10). Information on the operation and physical attributes of such structures will be instrumental in any future Level 2 analyses.

Box 10. Hydrologic impacts of reservoirs

In 1963, Glen Canyon Dam began to store water, and Lake Powell reservoir was created along the Colorado River. Since then, the Colorado River downstream of the dam has not experienced its natural seasonal floods. Snowmelt produced pre-dam flood flows on the Colorado on the order of 2,400 m^3/s. Since 1963, the controlled releases from the Glen Canyon Dam have generally been maintained below 500 m^3/s. In addition to modifying the streamflow, dams impede the transport of sediment downstream by trapping it behind the dam (Poff et al. 1997).

◀ Channel

Identify and map areas with channel modifications. Extensive levees, diking, or bank armoring can disconnect the channel from its floodplain, which in turn can impact the hydrologic function of the watershed. Confer with the Channel analyst to determine the extent of channel modification.

Step 7. Characterize water use

Water use, through diversions of surface water or withdrawals of groundwater from wells, reduces streamflow, potentially resulting in a negative impact on biological resources. Water use is generally categorized by beneficial use designations, such as municipal water supply, industrial water supply, irrigated agriculture, domestic water supply, fish and wildlife, recreation, and federal reserved rights.

Identify the types of beneficial water uses in the watershed and summarize them in a table. If overuse of either surface water or groundwater was identified as a concern during Scoping,locate areas of concern in the watershed. For instance, several areas in the country have pumped groundwater resources excessively, to the extent that the land surface is subsiding.

Water Quality

Make generalizations about the typical schedules of withdrawals for each beneficial use. For instance, withdrawals for irrigation may only be operated for a few months of each year, while withdrawals for water supply are typically year round. Characterize the surface water withdrawals separately from the groundwater withdrawals. Determine, if possible, how much of the water use is consumptive (Box 11) and the extent of imports of water from or exports of water to other watersheds (interwatershed transfers).

Box 11. Consumptive water use

Consumptive use is the quantity of water absorbed by a crop and transpired or used directly in the building of plant tissue together with the water evaporated from the cropped area.

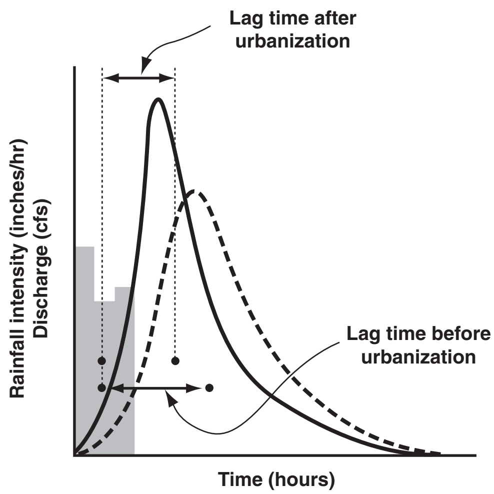
Section 2. Screen for Potential Land and Water Use Impacts on Hydrology

The screening process is designed to focus future analyses by identifying land and water use activities in the watershed that are potentially problematic. Land use practices and structural features, as well as water use, can modify the hydrologic regime of a watershed by altering one or more of the following:

- Amount of water available for runoff.
- Flow available in the channel.
- Routing of water to the streams.
- Lag time (delay between rainfall and peak streamflow; Figure 5).
- Travel distance to the stream.

Each activity has its own array of potential impacts to the hydrologic resources (Table 1). Those activities that affect the rate of infiltration or the ability of the soil surface to store water are typically most influential. For instance, impervious surfaces associated

Figure 5. Hypothetical hydrographs demonstrating changes between pre-urbanization (dotted curve) and post-urbanization (solid curve) runoff



Adapted from Leopold (1968)

with urbanization inhibit infiltration, causing rain to run off more quickly, as shown in Figures 5 and 6 and described in Box 12.

The screening steps will draw on the information gathered in the characterization section and offer guidance for the analyst to determine which potential land or water use issues warrant further investigation. For each sub-basin, enter a "Yes" or "No" under each use category on Form H2. A "Yes" on Form H2 indicates that a potential for hydrologic impacts exists for the use in the sub-basin. A "No" indicates that either the use does not occur in the sub-basin or that the impact is projected to be minimal. In addition, the last column on Form H2 encourages comments on the rationale behind each screening response.

Box 12. Example of urbanization impacts

Urbanization causes the peak flow (highest point on the curve) to increase and to occur sooner (the lag time has decreased), as shown in Figure 5. The same concepts are shown in Figure 6, where two streams respond differently to the same rainstorm: one stream drains a forested watershed, and the other drains an urbanized watershed.

Keep in mind that the work completed in this screening is not definitive. More detailed technical analyses are necessary to verify the presence of

Figure 6. A typical annual hydrograph based on mean monthly flow values

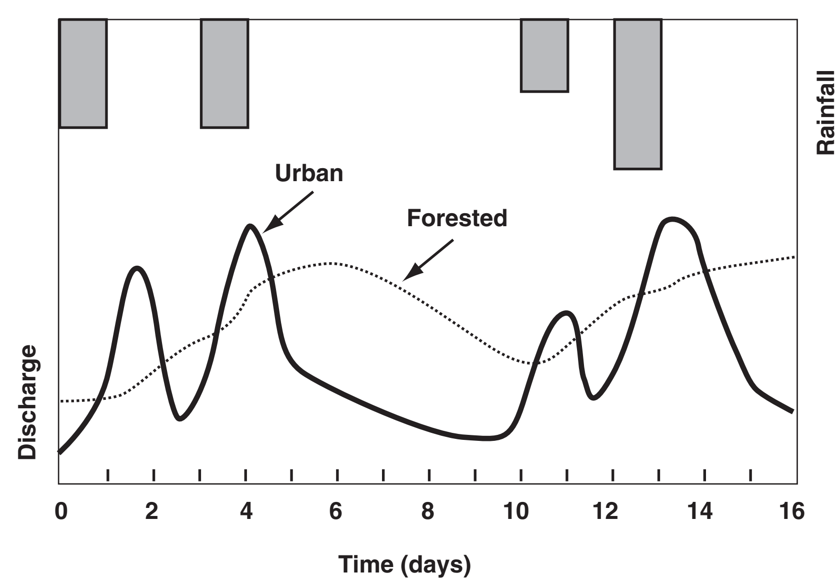


Table 1. Potential hydrologic effects associated with land and water use

Land Use	Land Use Practice	Hydrologic Component Affected	Potential Hydrologic Effects
Forestry	Timber harvest	Peak flow	Increased peak flows due to reduction in evapotranspiration and interception as well as more accumulation and melt of snowpack. Diminished impact as regrowth occurs even though damage to the channels may persist.
		Low flow	Increased low flows due to reduction in evapotranspiration and interception.
	Roads and harvest practices	Peak flow	Rerouted subsurface flows to surface runoff through roadside drainage ditches. Compaction of soil causes increased runoff and decreased infiltration. Logging practices such as skid trails contribute to the same effect.
		Annual yield	Increased water yield due to more accumulation of snowpack in open areas and reduction in evapotranspiration and interception. Most of increase occurs during wet part of the year.
Agriculture/ rangeland	Land drainage through ditching	Peak flow	Increased timing of storm runoff as surface flow moves more quickly to stream.
		Low flow	Lowered water table. Reduced groundwater recharge.
	Draining wetlands	Peak flow	Increased timing of storm runoff as surface flow moves more quickly to stream.
		Low flow	Lowered water table. Reduced groundwater recharge.
	Crop production	Low flow	Altered rates of transpiration affects runoff.
	Cattle grazing	Peak flow	Increased timing of storm runoff due to compaction of soils. Reduced infiltration.
Urban	Increase in impervious surfaces	Peak flow	Reduced infiltration. Surface flow moves more quickly to stream, causing peak to occur earlier and to be larger. Increased magnitude and volume of peak. Can cause bank erosion, channel widening, downward incision, and disconnection from floodplain.
		Low flow	Reduced surface storage and groundwater recharge, resulting in reduced baseflow.
	Use of stormwater facilities	Peak flow	Increased timing of runoff through increased velocity due to lower friction in pipes and ditches. Surface flow moves more quickly to stream via pipes and ditches, causing peak to occur earlier and to be larger. Increased total volume.
Water control structures	Dams and diversions	Peak flow	Reduced magnitude and frequency of high flows. Can cause channel narrowing downstream of dam. Capture of sediment behind the dam can result in downstream channel erosion and bed armoring.
	Levees and channelization	Peak flow routing	Reduced overbank flows. Isolation of the stream from its floodplain. Channel constriction can cause downcutting.
Water use	Surface water diversions	Low flow	Depleted streamflow by consumptive use. Streamflow depleted between point of withdrawal and point(s) of return.
	Groundwater pumping	Low flow	Lowered water table. If hydraulically connected, can cause streambank erosion and channel downcutting after loss of bank vegetation.
	Return flow	Low flow	Altered timing of groundwater/surface water interaction.

problems and to determine the magnitude of impacts. Outlining a detailed assessment process that relies on hydrologic techniques is beyond the scope of this document; however, general guidance for more extensive analyses is provided in the "Level 2 Assessment" section.

Step 1. Summarize land uses

Inspect the land use map from the Scoping process and identify the land uses present in each sub-basin. Validate the boundaries around the mapped land uses using aerial photos, orthophotos, or topographic maps and correct any inaccurate boundaries. Use this corrected land use map to determine the area (acres or mi^2) of forestry, agriculture, rangeland, urban, rural residential, and other land uses in each sub-basin. The areas in each land use can be determined using GIS, calculated using a planimeter, or estimated using the rectangular grid method. Identify the location of structural features on the map, and identify the point of diversion for each significant water use.

Enter the area estimated for each land use in each sub-basin into a table similar to Figure 7.

Figure 7. Sample table format for summarizing land use data

	Land use categories (% of watershed area)					
Sub-basin name	Forestry	Agriculture	Rangeland	Urban	Rural residential	Other
Entire watershed						

Step 2. Screen for potential forestry issues

If commercial forestry is a land use activity in the watershed, then the existing condition of the forest stands in the watershed will need to be assessed. Further investigation will be needed if the canopy cover of the current forest stand is substantially different from its historical condition. In addition, extensive harvesting within the last few decades may have substantially impacted the hydrology. Confer with the Vegetation analyst to obtain work products and general information on the changes in forest canopy over time. Consult with agency hydrologists or foresters as needed to determine whether regional criteria for harvest management are available or whether there are regional forestry issues that need to be addressed. For instance, much of the timber harvest in the southeastern United States comes from lands occupied by a high percentage of forested wetlands. Impacts of timber harvest on hydrology in this region should specifically address wetlands.

Vegetation ▶

For sub-basins in which commercial forestry raises concern, enter a "Yes" on Form H2. Further investigation may not be warranted if forestry occupies only a small portion of a sub-basin or the vegetative cover condition has not changed substantially; in this case, a "No" may be the appropriate response on Form H2. For sub-basins in which no commercial forestry occurs, enter an "N/A" on Form H2.

Step 3. Screen for potential agriculture or rangeland issues

If agriculture activities or rangeland management occurs in a sub-basin, several questions regarding soil type and agricultural practices will need to be addressed. The impact of agriculture on hydrology is dependent on specific practices such as the type of cover and management treatments, as well as the characteristics of the soil being farmed (Box 13). The infiltration rates of undisturbed soils vary widely. Agriculture has a greater effect on runoff in areas where soils have a high infiltration rate than in areas where soils are relatively impermeable in their natural state (USDA Soil Conservation Service [SCS]1986). Impacts associated with the utilization of rangelands can be assessed in a manner similar to that used for agricultural lands. In addition, cattle grazing on sparsely forested lands can have similar impacts and should be considered under this heading.

Box 13. Example of a regional agriculture issue—peat mining in North Carolina

A study on the Coastal Plain of North Carolina (Gregory et al. 1984) found the following hydrologic impacts associated with peat mining:

- Greater volume, duration, and peak flow of storm discharge from the field ditches on the mining sites than from sites with natural vegetation.
- Quicker overland flow to the ditches on the mining site due to reduced infiltration associated with grading the surface.
- Lower baseflows in the ditches draining the mined sites.

Erosion

The USDA has characterized and mapped the soils for most areas across the United States. Other agencies, such as state land managers and the USFS, are also sources of soil information. As part of the mapping process, soils are classified into one of four hydrologic soil groups (Table 2), primarily as a function of their minimum infiltration rate on wetted bare soil. Confer with the NRCS specialist nearest the watershed to locate soil group information, typical agricultural practices in the watershed, and any regionally specific crops.

Use the percentage of the sub-basin in agriculture, knowledge of associated soil groups, and typical agricultural practices to help determine whether agricultural concerns exist. Enter a "Yes," "No," or "N/A" response on Form H2 for each sub-basin.

Table 2. Hydrologic soil group classification

Hydrologic soil group	Characteristics of soils	Minimum infiltration rate (mm/hr)
Low Runoff Potential A	High infiltration rates even when thoroughly wetted. Deep, well drained sands or gravels with a high rate of water transmission. Sand, loamy sand, or sandy loam.	8 - 12
B	Moderate infiltration rates when thoroughly wetted. Moderately deep to deep, moderately well to well drained, moderately fine to moderately coarse textures. Silt loam or loam.	4 - 8
C	Slow infiltration rates when thoroughly wetted. Usually has a layer that impedes downward movement of water or has moderately fine to fine textured soils. Sandy clay loam.	1 - 4
D High Runoff Potential	Very low infiltration rate when thoroughly wetted; chiefly clay soils with a high swelling potential; soils with a high permanent water table; soils with a clay layer near the surface; shallow soils over near impervious materials. Clay loam, silty clay loam, sandy clay, silty clay, or clay.	0 - 1

SCS (1986)

Step 4. Screen for potential urban, suburban, or rural residential issues

For sub-basins with urban, suburban, or rural residential development, the screening process will rely on estimating the impervious area as the basis for determining potential hydrologic impacts. Impervious surfaces are those that prevent or inhibit the natural infiltration process, such as roads, parking lots, and roof tops. Table 3 displays the average percentage impervious area associated with various types of development. For each sub-basin, use the land use map and aerial photos to estimate the area occupied by the most common types of development. Multiply this area by the average impervious area percentage from Table 3 to obtain an estimate of the sub-basin total impervious area (TIA). If it is not possible to identify the areas of development types, a TIA estimate can be made based on road density (Box 14).

Table 3. Average area of impervious surfaces, urban and residential development

Type of land development	Average impervious area (%)
Urban Districts:	
Commercial and business	85
Industrial	72
Residential Districts by Average Lot Size:	
1/8 acre or less (town houses)	65
1/4 acre	38
1/3 acre	30
1/2 acre	25
1 acre	20
2 acre	12

SCS (1986)

Optional Task: Compute the weighted average percentage impervious value for all development types in the sub-basin.

Box 14. Using road density to estimate impervious area

If difficulties arise in estimating impervious areas, the extent of development can often be expressed in terms of road density. May et al. (1997) established a relationship between watershed urbanization (percentage TIA) and sub-basin road density (mi/mi^2) that can be used as a surrogate for percentage impervious surfaces in the Pacific Northwest. In urbanized areas of the Pacific Northwest when road densities equal or exceed 5.5 mi/mi^2, TIA probably exceeds 10 percent.

Concern for potential urban-related hydrologic issues should arise for each sub-basin that exceeds a regionally appropriate percentage impervious area threshold. For Puget Sound Lowland streams in Washington, May et al. (1997) recommend that impervious area be limited (< 5-10 percent TIA) to maintain stream quality, unless extensive riparian buffers are in place. Consult agency hydrologists or research in the vicinity of the watershed to develop a threshold of concern applicable to the watershed. Schueler's (1994) review of 18 urban stream studies revealed that a sharp decline in species diversity was often associated with 10 percent or greater TIA.

Based on the estimated total impervious area in the watershed, designate sub-basins in which urban use is of concern by entering a "Yes" or "No" response on Form H2.

Step 5. Screen for potential water control structure issues

For sub-basins with man-made water control structures and storage facilities, determine the portion of the watershed influenced by each structure. Each reservoir has its own operating scheme and, therefore, will require more detailed hydrologic investigations, often including release schedules, reservoir routing, etc. If there is a sizable reservoir in the watershed, further technical analyses will be required for the portion of the watershed below the dam, but some of the steps can be completed for the land uses present in the portion of the watershed above the dam. Consult with hydrologists at the Bureau of Reclamation, USACE, public utilities, or local reservoir operators to obtain information about the operating scheme.

Channel

Other types of structures, such as dikes, levees, or channelization, can affect the hydrologic function of a watershed because they modify channel configuration. Confer with the Channel analyst to assess reaches of concern.

In consultation with agency hydrologists and using data collected in the characterization section, determine the extent to which the structures may be altering the hydrology of the watershed. Sub-basins in which structures may cause changes to the hydrology will require further study and should receive a "Yes" response on Form H2.

Step 6. Screen for potential water use issues

For sub-basins in which water is being withdrawn from either surface or groundwater, comparisons of stream flow to water use will be necessary. Determine the time of year when water use is the highest. If possible, compile estimates of monthly water use based on information collected in Step 7 of Section 1.

In many regions throughout the country, high demand for water occurs during the low flow season. The reduction of streamflow due to water use is of particular concern during the low flow season. Consider whether a pattern emerges when comparing monthly streamflow to monthly water demand.

Further investigation of water use and allocation issues may be warranted if consumptive use is high in one or more sub-basins, particularly if the low flow period coincides with times of high water use. In addition, while the impact to low flows of a surface water withdrawal is fairly straightforward to account for and immediately felt, the impact of groundwater withdrawals on nearby streams is not as easily understood. Characterizing the groundwater/surface water interactions (termed hydraulic continuity) may be necessary in areas where water use and water supply requirements are competing with fisheries protection measures, such as enforcing minimum in-stream flows.

In consultation with agency hydrologists and using data collected in the characterization section, determine the extent to which water use is depleting streamflow. Sub-basins in which water use may be a concern will require further study and should receive a "Yes" response on Form H2. Sub-basins with minimal water use may not need further study.

Step 7. Produce Hydrology report

Generate a brief report summarizing the information gathered. The report should feature the tables, graphs, and forms produced as well as a narrative describing the hydrologic and climatic character of the watershed and the potential land and water use impacts.

Level 2 Assessment

Once the initial watershed characterization and the screening for potential impacts have been completed, the focus of future assessment efforts should be reasonably clear. This section provides a general discussion of available options for Level 2 characterization and analyses. The Level 2 methods and specific tools required will differ for each watershed depending on issues revealed during the Level 1 assessment. Level 2 analyses will be more technical and extend the level of detail beyond that used in Level 1 (see Hydrology Module Reference Table).

Level 2 Characterization

Streamflow patterns

The methods for a Level 2 characterization of streamflow will be a function of available data and Level 1 products. For Level 2 analyses, determination of streamflow for each sub-basin will be necessary to assess the patterns and trends over time. Level 2 methods may include the following:

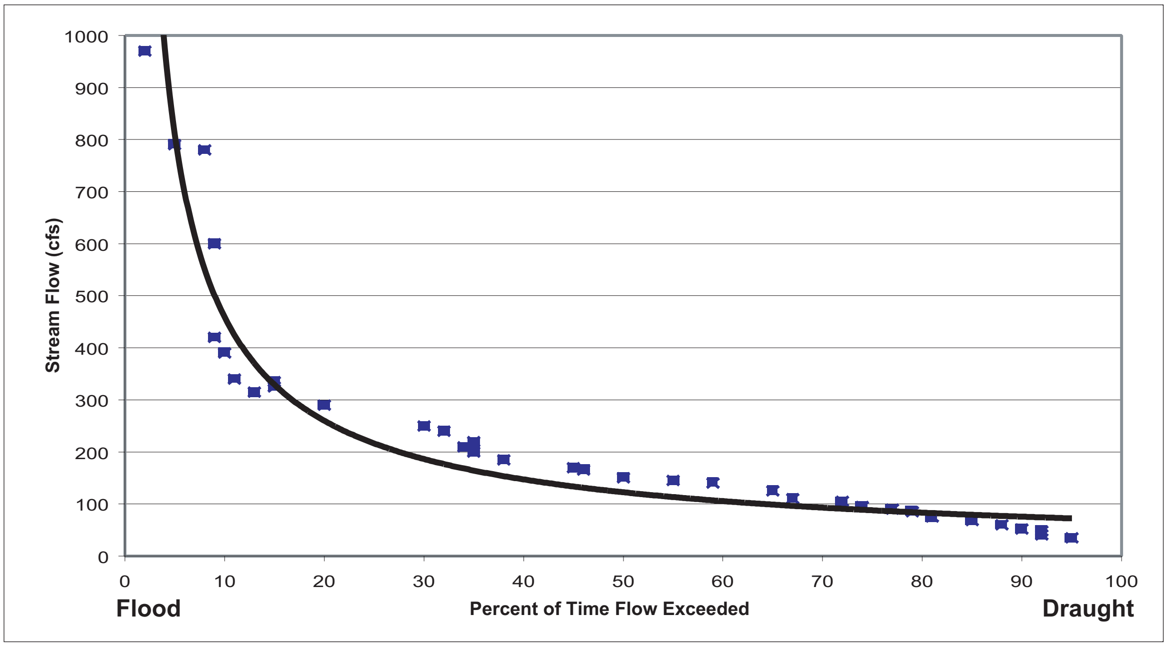
- Applying streamflow statistics from one gage location to another point in the watershed (e.g., applying unit runoff from an upstream point to the mouth of a watershed).
- Using regional regression equations for watersheds that are ungaged and have no streamflow records.
- Using correlation techniques for stations with short periods of record and extending them using long-term data from another gage that drains a hydrologically similar watershed.

Statistical information on extreme events generated through flood frequency analyses (e.g., log pearson type III), low flow frequency analyses, or $7Q^{10}$s can provide perspective on the range of expected extreme flows. Frequency analyses can be performed using annual peak flow series data or partial series data.

◀ Aquatic Life
Water Quality

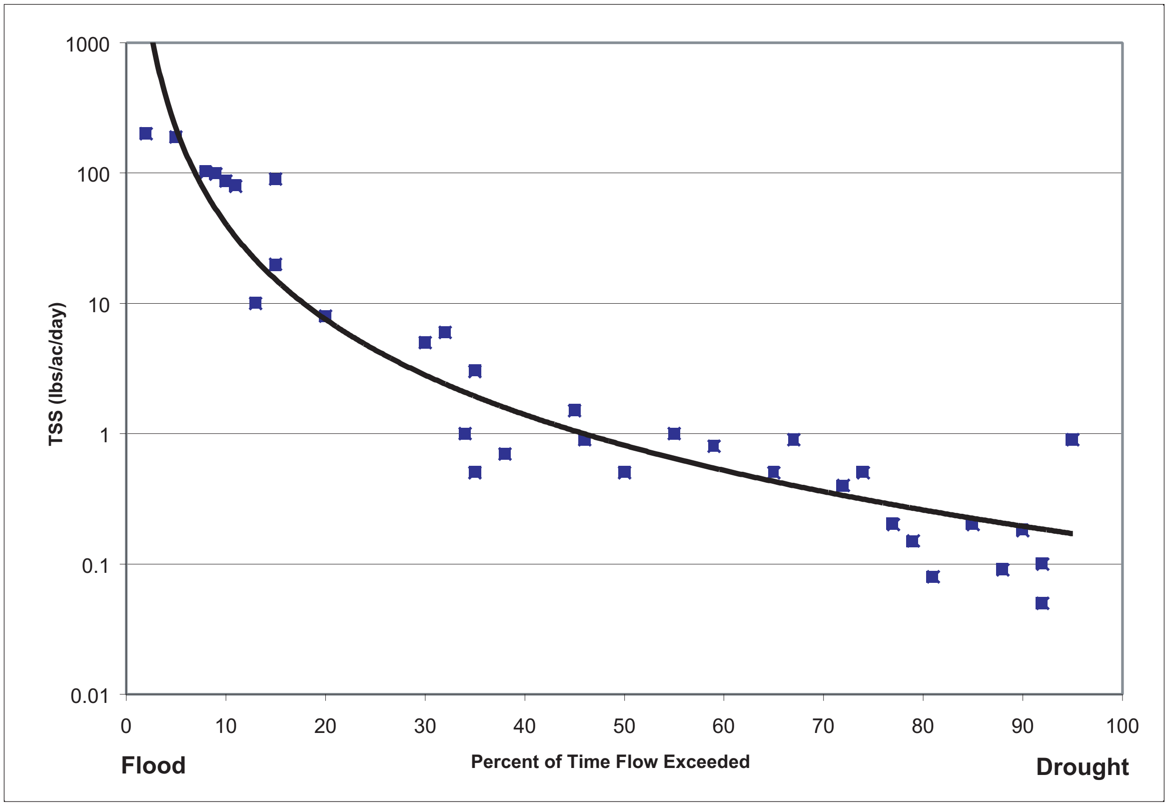
Flow duration curves provide an excellent way to represent streamflow data to better target pollution sources and effective management strategies. A flow duration curve is the cumulative frequency of stream flow without regard to the chronology of occurrence (Leopold 1994). Flow duration curves represent the percentage of time a given value of stream flow will be exceeded (Figure 8). Thus, the highest streamflows on record (i.e., flood conditions) will correspond to the lowest percentages, whereas the lowest streamflows (i.e., drought conditions) will correspond to the highest percentages. Duration curves generally reflect average daily flows but may also represent weekly or monthly flows.

Figure 8. A hypothetical example of a flow duration curve based on mean daily stream flow.



Since nonpoint source pollution is often driven by runoff events, watershed management plans or TMDL development may need to target different factors across the range of flow conditions to restore water quality (Cleland 2002). Flow duration curves can help to diagnose the source of problems and target specific activities or areas for improvement. For example, if exceedence of water quality criteria occur at low flows, point sources of pollution are likely to be targeted, whereas if exceedence occurs at high flows, nonpoint sources and land management activities may need to be targeted. Figure 9 provides a hypothetical example showing higher suspended sediment values at high flows, potentially indicating a problem with non-point sources of sediment or bank erosion. Flow duration curves may also be useful in evaluating pollutant load trading to ensure that the timing and amount of pollutant load exchange provides adequate water quality protection. Flow duration curves may be particularly helpful in providing insights for the Aquatic Life and Water Quality modules."

Figure 9. A hypothetical example relating the annual flow duration curve with suspended sediment pollutant load.



Precipitation patterns and other climate data

Data from additional precipitation and snow stations can help to further characterize the precipitation patterns and their influences on the hydrologic regime. Data from more than one station along with NOAA maps or PRISM (Parameter-elevation Regressions on Independent Slopes Model) maps developed by Oregon Climate Service (**http://www.ocs.orst.edu/**) can be used to determine precipitation distribution throughout each sub-basin. Multiple station data can also be useful for evaluating the impacts of elevation and aspect on hydrologic processes such as rain, snow, or a combination thereof. Precipitation frequency analyses reveal the magnitude and frequency of extreme precipitation events. Level 2 analyses typically rely on additional climate data such as temperature, wind, and evaporation data.

Trend analyses

Level 2 analyses may involve detecting trends in the streamflow or climate parameters. A trend can be defined as a systematic increase or decrease over time of one particular parameter (e.g., streamflow or temperature). Several options for detecting underlying trends in time-series data sets are available. The first step is often to perform some type of smoothing technique such as a moving average to reduce the effects of non-systematic variation in flows. Moving averages can be calculated for different time periods (e.g., 5-year or 10-year moving averages) depending on the availability of data. The Mann-Kendall nonparametric test can be used to discern monotonically increasing or decreasing trends in streamflow or precipitation data (Maidment 1992).

A double mass analysis is useful for the detection of changes in relationships between two monitoring stations. This may become important if the location of a station has changed over its period of record or if a change in land use practices has occurred around one station but not the other.

Groundwater and other natural storage

Level 2 analyses may require further definition of groundwater issues. The average daily hydrograph of surface water can be used to evaluate baseflow characteristics that are usually supplied by groundwater discharge. Groundwater/surface water interactions can be qualitatively addressed by examining a graph of the logarithm of discharge versus time. The slope of the recession on this graph indicates the role of groundwater in sustaining baseflows. The groundwater component of streamflow can also be evaluated using a computer-based hydrograph separation technique (such as HYSEP [Sloto and Crouse 1996]) or summary statistics from the daily minimum streamflow records. Surficial aquifers can be delineated and mapped based on comparisons of physical properties such as depth to groundwater, surficial geology, soil properties, and the presence or absence of near-surface aquitards (geological strata that limit groundwater seepage).

Monthly or daily tracking of hydrologic components in a water budget may provide more information on the state of the water table fluxes, the lags between storage components, and ultimately, the impact of groundwater and other storage on streamflow. This can be accomplished using a spreadsheet or a watershed hydrologic model such as BASIN (see Table 4 in the "Land Use" section, below).

Runoff generating processes

The compilation of daily streamflow and climate data for the duration of typical storms can be useful for further characterizing the watershed's runoff response. For instance, in areas where rainfall duration has a large influence on producing watershed runoff, daily precipitation values for several days prior to and including the day of the annual peak flows will be helpful in detecting patterns. In other areas where rainfall intensity may strongly influence the generation of runoff, collection of data on the rates of rainfall throughout a day may offer insight into watershed processes.

In still other areas, runoff may result primarily from the combination of rainfall and water resulting from snowmelt during the storm. Collection of temperature and snowpack data prior to and during the time of annual peak flow events will help to determine the propensity for snowpack to contribute melt water during storms; these storms are referred to as rain-on-snow events.

Level 2 Analysis

Water control structures

Level 2 analyses of water control structures will include techniques tailored to the physical setting and operating scheme of each structure. Reservoir routing, watershed modeling, and other techniques may be necessary to assess impacts of different operating rules on downstream flows or to deregulate streamflow records. Supporting statistics can be generated to respond to specific inquiries. For example, the Kootenai Tribe of Idaho posed the following question: Has the dam changed the season in which floods typically occur (Box 15)? Other questions may arise regarding changes to the magnitude of flooding. For larger, multi-purpose reservoirs, operators typically employ continuous hydrologic models to forecast inflows, estimate lake levels, and schedule outflows. These models have been calibrated to the watershed and may provide a useful tool for the Level 2 assessment.

In watersheds with numerous small diversion structures, water use may become the focus such that Level 2 analyses will need to include quantification of the cumulative impacts numerous withdrawals may have on seasonal low flows.

Water use

Box 15. Analysis of dam effects on the Kootenai River, Idaho

The Kootenai Tribe of Idaho recently completed a Kootenai River Watershed Assessment (Sasich et al. 1999). As part of this assessment, impacts of a dam were investigated. The table below summarizes the number of peak flood events in the pre-dam period compared to the post-dam period. The analysis was completed for three time categories that represent critical life stages for the aquatic species of concern in the watershed. This investigation demonstrates that the temporal sequence of floods has been substantially altered by the dam operations; a higher percentage of floods has occurred from November to March in the post-dam period than in the pre-dam period. Also, more floods occurred in the pre-dam period between April 15 and June 30 than after the dam was constructed.

Peak Floods at Leonia Gage (includes annual and partial series data)

	Pre-dam (water year 1929-71)		**Post-dam** (water year 1972-98)	
Time period	**Number of floods**	**% of total**	**Number of floods**	**% of total**
April 15 - June 30	90	92	9	32
July - October	7	7	7	25
November - March	1	1	12	43

A relatively easy way to initially characterize water use in a watershed is to tabulate the designated beneficial uses for both the surface and groundwater rights that are on file with the state agency responsible for water law administration. Water rights have different entitlements across the country depending on the water law in effect (Box 16). Understanding the implications of the applicable water law will be necessary for completing a Level 2 analysis.

Box 16. Water law and water rights

Currently, 29 eastern states utilize the riparian rights system, in which a landowner is entitled to the use of the water bordering his or her property. Water law in the western states is based on the prior appropriation doctrine or "first in time, first in right." Approximately 10 states use a hybrid system that combines attributes from the riparian rights and the prior appropriation doctrine. The prior appropriation doctrine entitles the most senior appropriators to divert water prior to any water rights holders with a later date (junior). Indian reservations, national forests, national parks, and BLM lands are all examples of federal reservations. These entities maintain federal reserved rights for the purposes for which the reservation was established and the priority date of the water right is the date the reservation was established.

Water rights, diversions, and use can be tracked by employing a water allocation model or a spreadsheet depending on the complexity of the situation. A water allocation model accounts for natural inflows, diversions, consumptive use (depletions), and return flows based on the state water laws. Output can provide the physical and legal availability of water for the reaches and time periods designated. A water allocation model tracks human uses of water while a hydrologic water balance model simulates the natural watershed processes that depend on climate inputs (precipitation, temperature, wind, solar radiation, etc.) and the physical parameters such as soil type and condition, geologic and topographic features, vegetative cover, and channel location.

Water allocation calculations can track the inflows and outflows of water, spatially and temporally. The spatial scale at which to operate a model must be carefully chosen. Calculating water allocation on an annual basis at the mouth of a river may show plenty of water. However, calculation at several locations in the same watershed on a monthly or biweekly schedule may reveal problems that a more aggregated water budget may mask.

In many regions, instream rights have become common as a means of protecting the biological resources. In-stream flows have been established and, in some cases, a water right has been awarded under the state agency in charge. In some states, in-stream flows are synonymous with minimum flows; however, many contend that in-stream flows should be set at a reasonable amount of flow to sustain biological resources, which is not the same as a minimum flow. Comparison of instream flow rights to the minimum flow records at several points in a watershed can help identify reaches of concern for fisheries and other biological resources.

Actual water use does not always measure up to the amount designated on water rights certificates. In some cases, illegal uses of water occur, abandoned rights exist, or certain rights are not used to their full extent. Collection of actual water use data can add more detail to a study aimed at the identification of reaches of concern. State departments of health, conservation districts, and agricultural extension offices are good sources of actual water use data as are records from the individual water purveyors in a watershed.

Investigations that address hydraulic continuity will be essential in some watersheds. The formulation of specific technical questions along with knowledge of the available data will assist in determining the approach for further hydrogeologic investigations. In some watersheds, the timing of potential surface water capture by groundwater may be important, while in other watersheds the analyst may only be interested in a spatial analysis that defines the zone of hydraulic connectivity to a certain surface water source. In areas where extensive groundwater data are available, a complex numerical model, such as ModFlow, can be employed to determine the magnitude, distribution, and timing of hydraulic effects.

Land use

Although it is fairly straightforward to identify the potential for a land use problem, attempting to quantitatively assess the magnitude of the problem or the hydrologic change is complex. The impacts of land uses on hydrology will vary from region to region and even from watershed to watershed. So too will the selection of appropriate analysis tools. Selection from the many options of technical tools will depend upon the available input data and the specific questions that need to be addressed. The available tools range in complexity from empirical equations to storm hydrograph methods to mechanistic hydrologic models operated on a daily time step or even finer detail. Table 4 identifies several techniques that may be useful, but it by no means constitutes a definitive list.

Continuous models can be applied at the watershed scale and may be necessary to assess cumulative impacts of several land uses in a watershed. For assessing urban impact from small, developed areas, unit hydrographs can be used (e.g., Santa Barbara Unit Hydrograph, Colorado Unit Hydrograph). Analysts assessing urban impacts may need the ability to route stormwater through drainage networks, while analyses of forestry impacts will need to address changes in forest cover as well as the differential accumulation and melt of snow. Snowmelt models may also be necessary in rangelands as snowmelt can often be an important element in many rangeland areas. In addition, the impact of the road network on the routing of surface water in rural and forest settings should be addressed in Level 2 analyses.

The single event hydrograph model TR55, based on the SCS runoff curve number technique, is probably the most commonly used tool applied to the agricultural setting. The curve number technique was originally developed for predicting changes in storm runoff volume associated with changing land management practices. More complex tools include BASIN, developed by the Bureau of Reclamation, Nebraska-Kansas Office. The BASIN program computes irrigation farm delivery requirements, project diversion requirements, groundwater diversion recharge, or watershed outflow, depending on how the model is configured. In addition, BASIN will compute streamflow depletions or net change in groundwater recharge due to a change in cropping patterns or irrigated acreage.

Keep in mind that many of the hydrologic tools and models suggested here (Table 4) are capable of evaluating impacts from several land uses while others perform well only for specific land uses. For example, TR55 was developed using data from small rural/agricultural watersheds and has proved useful in rural catchments for comparison of runoff under differing vegetative cover conditions. TR55 has not performed as well in steep forested watersheds where subsurface pathways are dominant (Fedora 1987). The applicability of many of the tools will be limited to the region in which they were developed, while others will be useable across the country.

Table 4. Examples of hydrologic tools for Level 2

Land use	Examples of hydrologic models or technical tools and contact entity
Forestry	• Washington State Watershed Analysis Methodology - Washington Forest Practices Board (WFPB 1997) • DRAINMOD/DRAINLOB - North Carolina State University • Antecedent Precipitation Index (API) - Oregon State University • DHSVM (Distributed Hydrologic Soils Vegetation Model) - Dennis Lettenmaier, University of Washington, Seattle, Washington
Agriculture/rangeland	• TR55 - NRCS • DRAINMOD - North Carolina State University • Basin - Bureau of Reclamation • Simulating Production and Utilization of Range Land (SPUR) - USDA • HFAM (Hydrologic Forecasting & Analysis Model) - Norm Crawford, HYDROCOMP, Inc., Palo Alto, California
Urban/rural residential	• Hydrologic Simulation Program Fortran (HSPF) - EPA • HFAM (Hydrologic Forecasting & Analysis Model) - Norm Crawford, HYDROCOMP, Inc., Palo Alto, California • Water Resources Evaluation of Nonpoint Silvicultural Sources Model (WRENSS) - USFS • PRMS (Precipitation Runoff Modeling System) - George Leavesly, USGS, Denver, Colorado • Regionalized Synthetic Unit Hydrograph methods (e.g. Santa Barbara, Colorado unit hydrograph) • Stormwater runoff network models (e.g., KYPIPE, WaterWorks)

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Form H1. General watershed characteristics

Watershed Name: ___________________________

Sub-basin information:

Sub-basin name	Sub-basin area (mi^2)	Mean elevation (ft)	Minimum elevation (ft)	Maximum elevation (ft)	Mean annual precipitation (inches)
Total watershed					

- Mean annual precipitation can be estimated from the Mean Annual Precipitation Map (from NOAA)
- Minimum and maximum elevations can be estimated from the base map or USGS quad maps.

Describe the type and extent of natural storage (lakes, wetlands, etc.) in the watershed.

What watershed changes have occurred that will affect streamflows (i.e., dams, major diversions for urban water supply, irrigation diversions, industrial use, etc.)?

Information on stream gages in watershed: (Note: if more than one gage, fill out additional forms.)

Gage #:
Gage name :
Gage elevation:
Drainage area to gage:
Storage or regulation upstream of gage (yes or no)? If yes, describe on back of sheet

Form H2. Summary of hydrologic issues by sub-basin

Sub-basin name	Potential forestry issue?	Potential agriculture or rangeland issue?	Potential urban or residential development issue?	Potential water control structure issue?	Potential water use issue?	Describe the rationale behind the responses
Entire watershed						

Channel

Background and Objectives

Stream channels are shaped by a number of important factors that interact to create characteristics unique to each stream. Some factors, such as the climate, geology, stream gradient, and drainage area of a stream, are typically unchanged by human activities. Other factors, however, such as the supply and transport of sediment, the character of riparian vegetation, and the volume and timing of water runoff can be influenced by land-use activities. These factors all influence the channel morphology and dictate the quality and quantity of habitat available for aquatic-dependent species. Studying channel morphology can thus provide a measure of changes in habitat conditions and together with the Aquatic Life module can help to assess the health of the aquatic system.

Evaluating the effect of land-use activities on channel conditions can be difficult because stream channels are affected by the interaction of many watershed processes that often have a great deal of natural variability. Large-scale projects such as dams or levees may create easily observed impacts on flood discharge and floodplain characteristics but may also have more subtle long-term impacts on important factors such as sediment storage, channel bed elevation, and nutrient transport. A great deal of field data collection and analysis may be necessary to provide evidence that land management impacts, and not natural disturbances such as floods, are responsible for a change in channel conditions. The Channel analyst will need to work closely with other analysts, particularly from the Erosion, Vegetation, Aquatic Life, and Water Quality modules, to conduct a comprehensive assessment.

The objectives for a Level 1 assessment are to characterize the types of channels that occur within the watershed and to identify where changes in channel morphology are most prevalent. The Level 1 assessment relies primarily on the analysis of topography, geology, and soil maps together with a historical set of aerial photographs. Some fieldwork is encouraged to verify channel characteristics observed on maps and photographs. Information on channel types within the watershed can be used to develop hypotheses about the cause of observed channel changes and potential future effects. Further evaluation and data will be necessary to provide evidence for any cause-and-effect relationships.

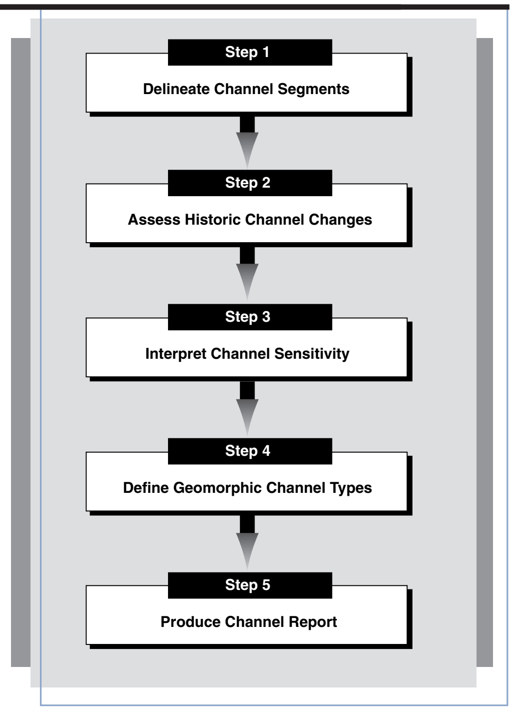
Level 2 methods and tools require specialized expertise and experience in evaluating channel behavior, conducting field surveys, and interpreting channel-related data. A Level 2 assessment may be necessary when multiple land uses are impacting the channel or when a defensible, quantitative analysis is required. Potential field methods include cross-sectional surveys to evaluate channel width/depth ratios, bankfull flows, hydraulic roughness, and substrate characteristics. More advanced and long-term evaluations may also involve measurement of discharge, bedload transport, and fine sediment transport. Analysis techniques can include sediment budgets, stream power calculations, and use of sediment transport equations and models.

Channel Module Reference Table

Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
C1: How does the physical setting of the watershed influence channel morphology?	• Air photos • Topography maps • Geology maps	• Anecdotal information • Observations from maps and air photos • Existing channel classification • Existing survey data • General channel typing	• Field surveys • Channel classification • Geomorphic channel typing
C2: How does climate and the frequency, magnitude, duration, and timing of floods affect channel conditions?	• Annual peak flow data • Climate data • Historical set of air photos	• Anecdotal information • Air photo observations • General channel typing	• Field surveys • Channel classification • Geomorphic channel typing • Flood analysis (Hydrology)
C3: How and where has the behavior of the channel changed over time?	• Historical set of air photos	• Anecdotal information • Air photo observations	• Field surveys • Channel classification • Geomorphic channel typing
C4: How and where have changes in sediment inputs (erosion) over time affected channel conditions?	• Historical set of air photos • Sediment source data	• Anecdotal information • Air photo observations	• Field surveys • Sediment budget • Soil Creep Estimation
C5: How and where have changes in riparian vegetation influenced channel conditions?	• Historical set of air photos • Riparian vegetation data	• Anecdotal information • Air photo observations	• Field surveys
C6: How and where have changes in stream discharge influenced channel conditions?	• Streamflow data • Historical set of air photos • Water withdrawal data	• Anecdotal information • Air photo observations • Hydrology data	• Streamflow models (Hydrology) • Bank erosion analysis (Erosion)
C7: What are the sediment transport characteristics of streams in the watershed?	• Sediment transport data • Streamflow data		• Suspended or bedload transport data • Sediment transport equations • Sediment budget (Erosion)
C8: Where does sediment storage occur in the channel and on the floodplain, and how much sediment is stored?	• Aerial photographs		• Field surveys • Aerial photograph analysis • Sediment budget (Erosion)
C9: How and where has the dredging, straightening or shifting of streams affected channel behavior?	• Historical set of air photos	• Anecdotal information • Air photo observations	• Field surveys • Sediment budget (Erosion)
C10: How does the presence and management of dams and levees affect channel conditions?	• Streamflow data • Historical set of air photos	• Anecdotal information • Air photo observations	• Reservoir models • Sediment transport models
C11: What is the potential for change in channel conditions based on geomorphic characteristics?	• Air photos • Topography maps • Geology maps	• Observations from maps and air photos • Existing channel classification • General channel typing	• Channel classification • Geomorphic channel typing • Field surveys

Level 1 Assessment

Step Chart



Data Requirements

- Topographic maps (1:24,000 scale [7.5-minute series] or finer preferred).
- Aerial photographs (1:12,000 scale preferred). Photographs recording major storm events and changes in land use activities are particularly useful for assessing changes in channel conditions.
- Geomorphic maps (if available).
- Landform map and erosion data (coordinate with Erosion module, if applicable).
- Land use map (as necessary).
- Climate and streamflow information (coordinate with Hydrology module).
- Information on water use/extraction and dam management (coordinate with Hydrology module).

Products

- Form C1. Historical channel changes
- Form C2. Geomorphic channel type characteristics
- Map C1. Channel segments
- Map C2. Geomorphic channel types
- Channel report

Procedure

Step 1. Delineate channel segments

Dividing the stream network into segments provides an initial interpretation of channel character that integrates the landform (i.e., geology, soils, and topography) and fluvial features of the valley with channel relief, pattern, shape, and dimension. A channel segment defines a portion of the stream network with relatively uniform channel features.

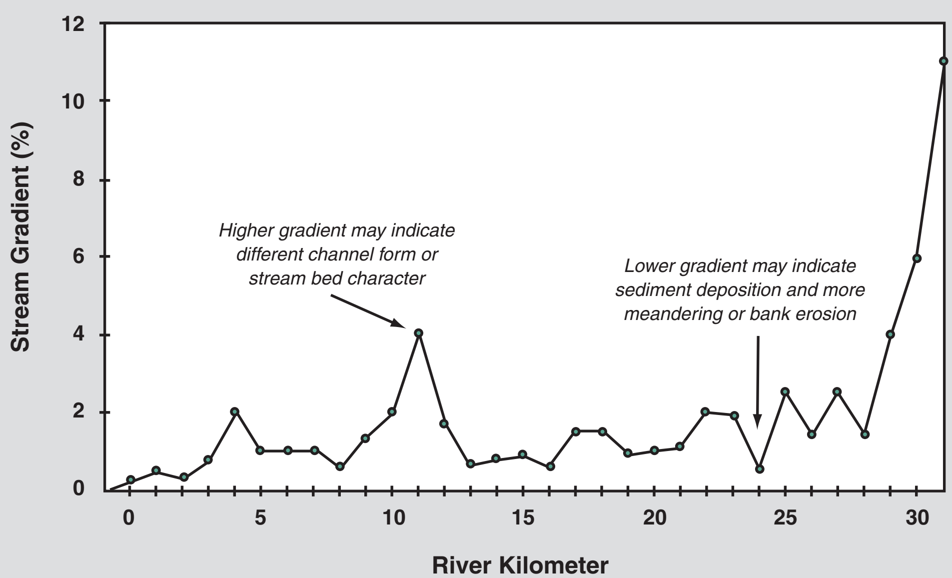
Using aerial photographs, topographic maps, and geology or soil maps, divide the stream network into segments by identifying locations where the channel characteristics change. Channel segments provide a preliminary classification system and serve as a reference for cataloging data and other observations. Characteristics that can be used to delineate segments include the following:

- Fault locations, major geologic structures, or changes in surface rock types.
- Inflow of major tributaries.
- Engineering structures, such as dams, diversions, levees, or single conveyance channels.
- Local variation in channel pattern.
- Channel confinement.
- Channel gradient (Box 1).

Box 1. Creating a Longitudinal Stream Profile

A relatively simple analysis of stream gradient can provide useful information for channel classification and highlight stream reaches that may require further study. Using a topographic map, determine the stream gradient at regular intervals for the entire length of the stream. Stream gradient is defined as the change in elevation divided by the length of the stream reach. Most streams have a generally increasing trend in slope as measured from the mouth of the stream to its headwaters. Abrupt increases in slope typically signify areas of higher stream energy and may indicate a change in confinement, geology, or sediment transport characteristics. Abrupt decreases in slope typically signify areas of lower stream energy and often correspond to areas of increased sediment deposition, broader floodplains, and greater stream meandering.

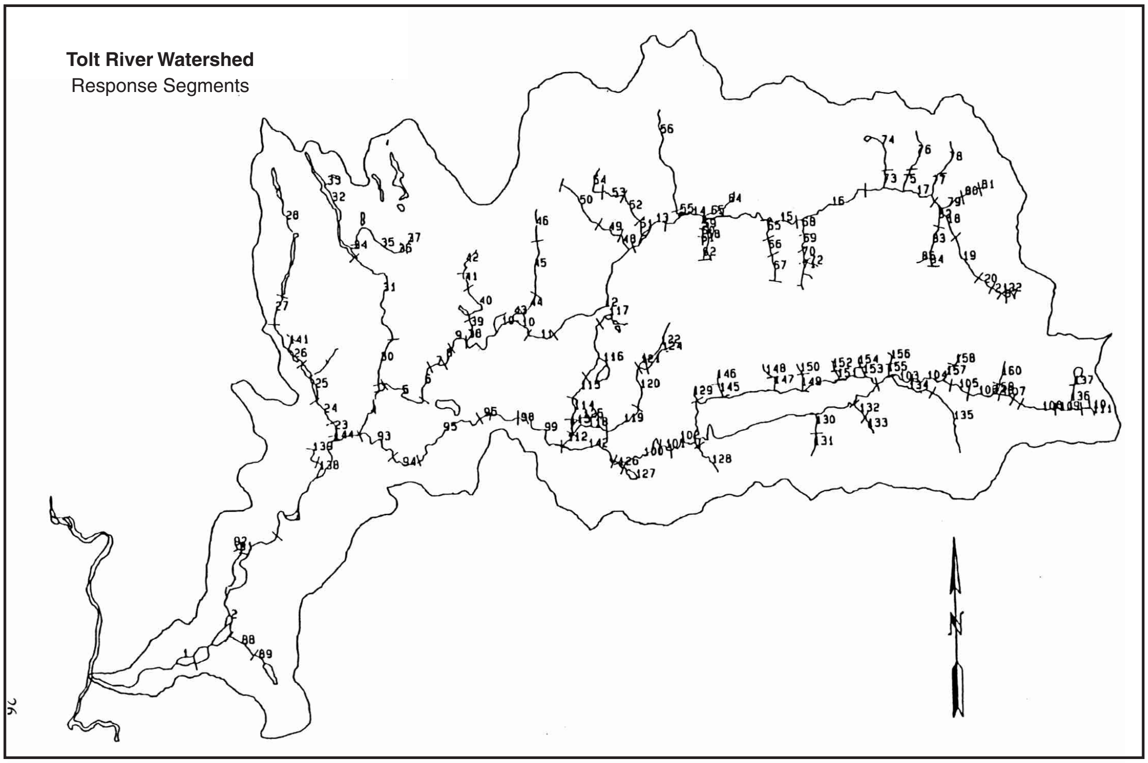
Longitudinal Profile for Bear Creek, Wyoming



- Changes in riparian vegetation.
- The presence, size, or shape of floodplains, terraces, fans, or sand/gravel bars.

Delineate channel segments on a topographic map to create Map C1 (Figure 1). In large watersheds with numerous tributaries, it may be useful to assign a numeric code to the mainstem channel and an alphanumeric code (e.g., A1) to each tributary system.

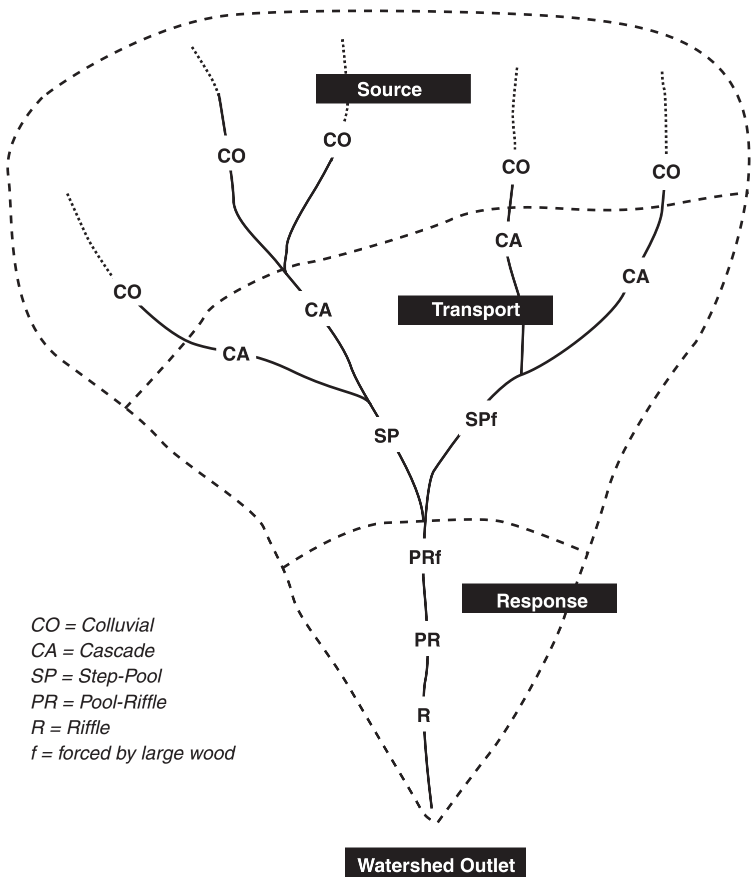
Figure 1. Sample Map C1



The length and number of channel segments will depend upon the watershed size and the goals of the Watershed Assessment. The analyst should not commit too much time to examining minor differences in channel character because more data will be collected to refine the channel classification.

Existing channel classification systems can also be used to delineate channel segments. Numerous classification systems exist that use one or more parameters to divide the channel network (Figures 2 and 3) (Graf and Randall 1997; Montgomery and Buffington 1993; Rosgen 1994; WFPB 1997). In most cases, the analyst will want to use the classification system that is most widely applied in the region. The

Figure 2. Watershed map illustrating application of stream classification based on stream gradient and morphology (Montgomery and Buffington 1993)



analyst should, however, evaluate the utility of using available classification systems to meet the WAM project goals. Considerations may include scale of investigation, available data, and the need for field data.

Step 2. Assess historical channel changes

A wide variety of historical data are useful for reconstructing past channel changes. In most cases, aerial photographs will provide the primary source of historical data. Photographic coverage that spans decades and records major events (e.g., floods, catastrophic events) is necessary to determine trends in channel conditions through time. The historical analysis is also the first step in developing hypotheses about channel response to management activities.

Historical changes and trends in channel attributes provide an important context within which to assess current and potential channel conditions. Aerial photograph analysis is an efficient method for focusing field efforts, as well as a valuable resource for indicating historical channel change and response.

Changes in channel morphology may involve the following elements:

- Engineering structures (diversions, levees, etc.).
- Channel pattern (e.g., sinuosity, braiding).
- Channel width.
- Size and form of sand/gravel bars.
- Extent and frequency of bank erosion.

Figure 3a. Stream types: gradient, cross section, plan view (Rosgen 1994)

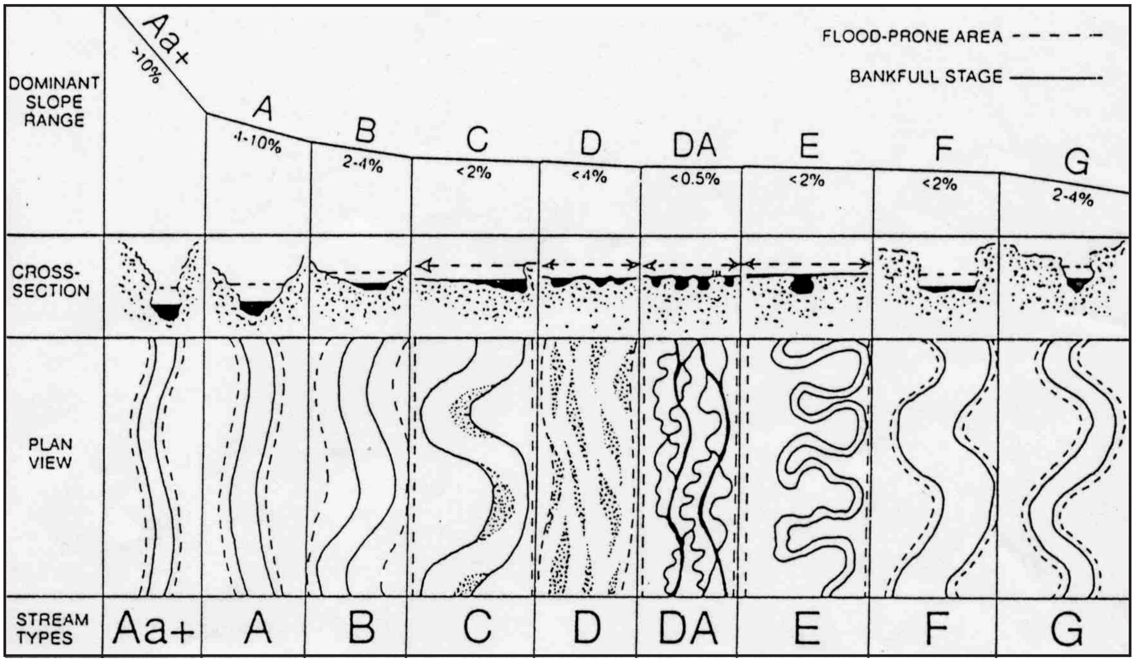
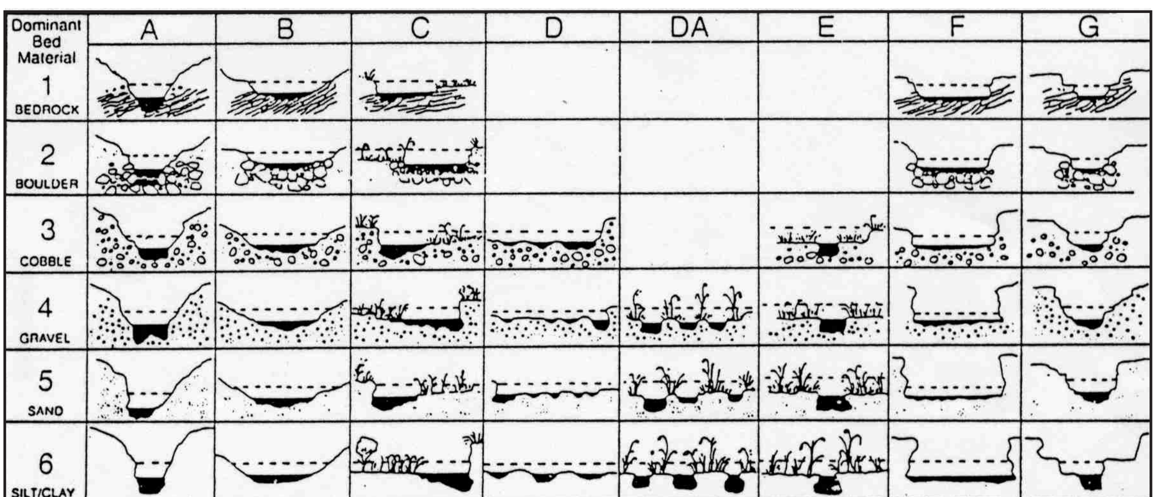


Figure 3b. Cross-sectional view of stream types (Rosgen 1994)



	A	B	C	D	DA	E	F	G
ENTRH.	<1.4	1.4-2.2	>2.2	N/A	>2.2	>2.2	<1.4	<1.4
SIN.	<1.2	>1.2	>1.4	<1.1	1.1-1.6	>1.5	>1.4	>1.2
W/D	<12	>12	>12	>40	<40	<12	<12	<12
SLOPE	.04-.099	.02-.039	<.02	<.04	<.005	<.02	<.02	.02-.039

- Areal extent and stability of floodplains, terraces, and fans.
- Scour from floods or channelized landslides.
- Wood debris loading.
- Canopy opening or changes in vegetation patterns.
- Sediment processes (local storage or erosion).
- Road crossings.

Hydrology

Reference points (i.e., fixed landmarks) should be identified so changes in channel dimensions and forms can be measured in successive aerial photographs. Measuring the same cross-sectional area (transect) allows the Channel analyst to compare changes in channel width and area over time. Measurements from different sets of aerial photographs will need to be corrected to account for scale differences and distortion. For small channels, direct observation of channel width may not be possible due to dense riparian vegetation. For these channels, canopy opening provides a useful surrogate for channel width (Grant 1988). In larger channels, changes in gravel bar size and vegetation cover may also be observed over time. To correlate channel changes with floods, coordinate with the Hydrology analyst. Where historical changes are observed, record observation on Form C1 (Figure 4).

Figure 4. Sample Form C1. Historical channel changes

Channel segment(s)	Historical changes	Other observations
1	Channelized with concrete banks since 1903	Radical changes have virtually eliminated aquatic habitat. Concrete channel minimizes influence of sediment, water, and vegetation.
2, 6	Levees since pre-1900	Dirt levees minimize sediment deposition. Flood scour compromises levee integrity.
3, 7, 11, 12, 13	Possible increased entrenchment	Interviews and aerial photos indicate channel incision over past 50 years, possibly due to removal of in-stream wood debris and increased runoff from urbanization.
4, 5, 9, 10	Increased sediment deposition and bank erosion	Low-gradient section with natural tendency for sediment storage and channel migration. Erosion from agricultural lands, grazing, and vegetation removal has probably increased sediment supply.

Step 3: Interpret channel responsiveness

Understanding the factors that control and influence channel processes is critical to the Synthesis step of the WAM process. The potential response of each channel segment to changes in sediment, water runoff, and vegetation will need to be evaluated in the context of historical channel behavior and the natural geomorphic setting (e.g., geology, gradient, valley confinement). Table 1 lists possible channel responses. The exact nature and duration of the responses will vary depending on the watershed and channel characteristics and the causes for the changes.

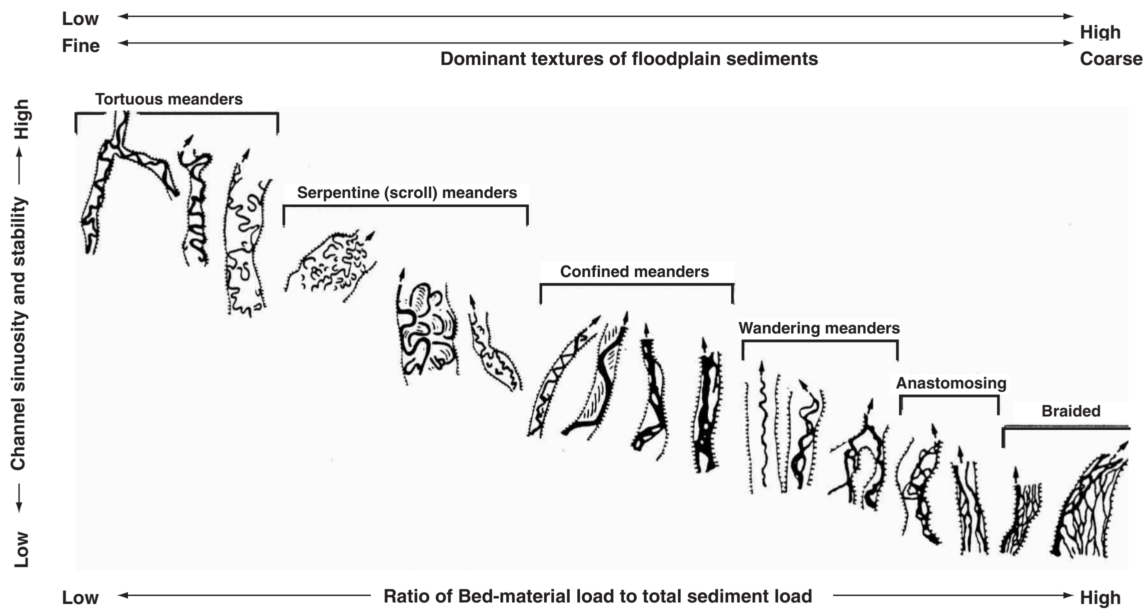
Table 1. Examples of potential channel responses to changes in water runoff, sediment supply, or vegetation

Change	Potential Channel Responses
Increasing water runoff	• Entrenchment (incision) • Gully formation • Coarsening of stream bed (i.e., less fine sediment) • Increased bank erosion
Decreasing water runoff	• Aggradation • Increased fine sediment in the stream bed • Decrease in channel width
Increasing sediment supply	• Aggradation • Larger, more frequent sand and gravel bars • Increased fine sediment in the stream bed • Increased channel movement • Increased flooding
Removal of upland vegetation	• Increased flooding • Increased sediment delivery
Removal of riparian vegetation	• Increased bank erosion • Aggradation • Fining of the stream bed • Increased channel movement • Channel widening

Considering evidence from aerial photographs, stream surveys, watershed reports, anecdotal information, and observations, identify channel segments that have shown a significant response to floods, vegetation disturbance, or changes in sediment supply (Figure 5). A change in channel behavior from natural or human disturbances generally signifies the potential for future changes at these channel segments. Consult with the Hydrology, Erosion, and Vegetation analysts to help correlate channel changes with large floods, periods of increased erosion, or substantial changes to upland or riparian vegetation. The analysts can provide useful information on the magnitude, frequency, distribution, and timing of changes in these watershed processes. The Historical Conditions and Community Resource analysts may also have useful information on past conditions or historical practices in and around the channel. Hypothesized connections between historical practices and changes in channel conditions will often require further Level 2 assessment to provide evidence for causal links.

Hydrology
Erosion
Vegetation
Historical Conditions
Community Resources

Figure 5. Examples of channel form as a function of gradient, particle size, and sediment supply



Adapted from Selby (1985)

In addition to considering external agents for channel changes, it will be important to consider the geomorphic setting of the channel to help evaluate where a high potential for change exists naturally. A longitudinal stream profile will often help to identify segments where a shift in gradient will increase the potential responsiveness of the channel. Evaluate whether changes in geology or soil type correlate with a change in channel pattern or behavior. Finally, examine the correlation between segments with a natural potential for responsiveness and evidence of historical changes in channel behavior. These correlations can be used to identify other channel segments with a high potential for responsiveness, even if these segments have not changed significantly in recent times.

Information on changes in channel behavior will be used in the following step to help define geomorphic channel types and to rate the responsiveness of channel types to changes in sediment, water runoff, vegetation, and other disturbances.

Step 4. Define geomorphic channel types

Defining geomorphic channel types relies on the work conducted in the previous steps, as well as products from other modules. Geomorphic channel types are groups of segments that have similar characteristics and that are expected to respond similarly to changes in water runoff, sediment, and vegetation. Channel typing can be useful to help integrate information on hillslope processes with information on channel conditions to ultimately assess aquatic habitat sensitivities.

Erosion
Hydrology
Vegetation

Specific criteria for developing channel types do not exist, so the Channel analyst must use available data and professional judgment to define appropriate categories. Channel types should consider both stream and valley form to characterize segments with similar geomorphic responsiveness. Group segments with similar channel conditions and potential responses to altered water runoff, sediment supply, or vegetation or to natural disturbances (e.g., floods, hurricanes, fire). Existing channel classification schemes (Graf and Randall 1997; Montgomery and Buffington 1993; Rosgen 1994; WFPB 1997) often consider many of these factors. A geomorphic channel type will typically consist of a group of channel segments, but a unique segment may warrant its own channel type. It may be helpful to consult with the Erosion analyst for a further understanding of the land types present in the watershed. Although the channel types are likely to be related to geomorphic land types, their delineation may not directly coincide.

Erosion

Creating geomorphic channel types provides a way of organizing information from the Channel module and other modules to describe linkages between hillslope processes and aquatic resources. Identification of channel types may involve some generalization such that some local reaches may not have the same response potentials as other reaches of the same type (WFPB 1997). Prior to the start of Synthesis, the Channel analyst should work with the other module analysts to interpret potential linkages between land use practices, changes in watershed processes, and channel responses.

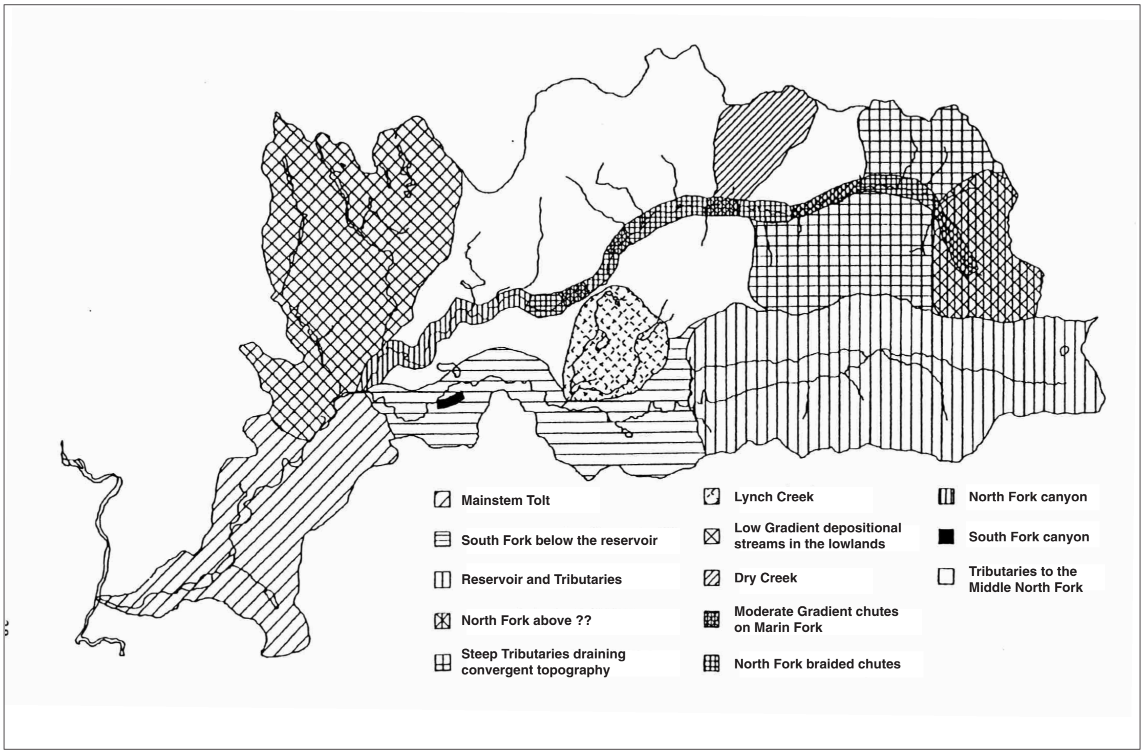
Erosion
Hydrology
Vegetation
Aquatic Life

Identify geomorphic channel types on Map C2 (Figure 6). Form C2 can be used to describe each channel type and summarize the hypothesized responsiveness of each channel type (Figure 7). Responsiveness for each channel type should be rated “High,” “Moderate,” or “Low” relative to changes expected in other channel types. Since the response potential of each channel type is based primarily on remote analysis of maps and other data, ratings should be considered preliminary. Field verification and further analysis will often be necessary to provide support for responsiveness ratings.

Step 5. Produce Channel report

The analyst should produce a report that organizes and presents the methods, data, and results of the Channel assessment. The report should include a brief narrative along with

Figure 6. Tolt watershed geomorphic channel types (adapted from Washington Forest Practices Board 1997)



tables, graphs, forms, and maps to provide the scientific justification for channel typing and responsiveness ratings. The type of data or information necessary for a high confidence level in the analyses and interpretations will not always be available; therefore, the analyst must address the confidence level of the data and work products. The degree of confidence that can be assigned to the products depends upon a number of factors:

- The amount, type, and quality of available information.
- The relative confidence for each work product.
- The extent of field work.
- The experience of the analyst.
- The complexity of the geology and terrain.
- Aerial photograph and map quality.
- Multiple lines of evidence for inferred changes.

Figure 7. Sample Form C2. Geomorphic channel type characteristics

Channel type	Description	Channel segments	Potential responsiveness rating			Evidence supporting rating
			Sediment	Runoff	Vegetation	
Lower Confined Mainstem	Low gradient (<1%), broad historic flood-plain, islands, river confined by levees	1 and 2	Moderate	High	Moderate	• Floods in 1980s undermined levees • Rip-rap instead of trees maintain river banks • Wetlands historically provided floodwater storage
Entrenched Mainstem	Low gradient (<1%), recent channel entrenchment	3	Low	Moderate	Low	• Historical floodplain not inundated during floods • Substantial bank erosion, but no change in pattern following floods in 1980s
Tributaries on River Floodplain	Low gradient (<2%), small meandering and braided streams, wetlands, and old oxbows common	A1, B1, and C1	High	Low	High	• Increased sediment supply could cause sub-surface flow • Root system from riparian trees maintain streambanks • Runoff spreads across floodplain
Tributaries in Naches Formation	2-4% gradient, entrenched, with high, raw banks in weak sandstone	A2, A3, C2, and D1	Low	High	High	• Floods cause severe bank erosion • Wood debris important for storing sediment
Meandering Upper Mainstem	2-6% gradient, gravel and cobble substrate, numerous rapids	4 - 8	Moderate	Low	Moderate	• Sediment not a problem, but more fine particles could change sub-strate character • Trees important for shade and bank stability

Level 2 Assessment

Stream channels are formed by a complex set of physical processes. Interpretations of channel conditions can be difficult because of the dynamic interactions among climate, water flow, and sediment transport. Determining natural or historical conditions is often a challenge because many streams have been significantly modified by human activities. Understanding the natural disturbance history can also be important for understanding current conditions. Evidence of channel disturbance from floods, landslides, or fires is often observable in channel and floodplain deposits for many decades following the disturbance.

Because of the complexity of channel processes, parameters used to assess stream conditions should be established in the scientific literature so that observations can be credibly supported. Parameters should focus on geomorphic forces that can be quantified (e.g., channel gradient, substrate size, shear stress) so that the analysis is repeatable and changes can be reliably measured. Ideally, parameters will be applicable to a wide range of channel types and account for variability from reach to reach. While some channel variables require long-term monitoring data, many useful parameters are relatively easy and inexpensive to measure in the field or from remote sensing.

The Level 2 assessment is divided into three general approaches to channel investigation:

1. Stream channel surveys.
2. Detailed channel classification.
3. Sediment budgets.

The following sections do not provide detailed instructions but offer general guidelines and references to other sources that elaborate on these procedures. The following books provide general information about channel processes and ways to evaluate them:

- *Rivers: Form and Process in Alluvial Channels* (Richards 1982).
- *Water in Environmental Planning* (Dunne and Leopold 1977).
- *The Fluvial System* (Schumm 1977).
- *Drainage Basin Form and Process* (Gregory and Walling 1973).
- *Fluvial Processes in Geomorphology* (Leopold et al. 1964).

Stream Channel Surveys

Field surveys are a critical element of any analysis of stream channel conditions. Fieldwork provides quantitative data on stream conditions that ideally can be extrapolated to evaluate conditions at a watershed scale. Field surveys can help with the following:

- Characterizing variation in channel features.
- Evaluating channel types.
- Applying or verifying channel classification schemes.
- Clarifying observations from maps and aerial photographs.
- Establishing reference sites to monitor changes in channel condition.

The number and location of surveys will vary depending on the objectives of the assessment and available time and resources. Where measurements are to be used for flow or sediment transport calculations, sites should be straight, single-stranded, and unobstructed to minimize complications. Where measurements will be used to compare conditions between streams, it will be important that characteristics such as gradient, substrate, and channel form are similar so that the effects of land management can be better isolated. Measurements for baseline and trend monitoring should be located in areas where change is likely and will be visible. In general, locally dynamic sites such as tributary confluences or alluvial fans should be avoided.

The following sections provide a brief description of techniques for examining channel variables. Detailed instructions on conducting stream surveys can be found in the following sources:

- *Stream Channel Reference Sites: An Illustrated Guide to Field Technique* (Harrelson et al. 1994).
- *Survey Methods for Ecosystem Management* (Myers and Shelton 1980).
- *Timber-Fish-Wildlife (TFW) Monitoring Program Method Manual for the Reference Point Survey* (Pleus and Schuett-Hames 1998).

Longitudinal and cross-sectional stream surveys

A stream reach can be characterized using a combination of longitudinal and cross-sectional surveys. The surveys should include a plan-view sketch of the stream reach and detailed notes on channel characteristics to help identify important benchmarks and measurement points. A surveyor's level and rod along with fiberglass tape can be used to map the location and elevation of important channel features. Channel features can include the stream gradient, bankfull width, bankfull depth, and floodplain features. Data on stream substrate, sediment particle size, and hydraulic roughness can also be collected at cross-sectional survey points (Box 2). The following paragraphs provide more information on measuring specific channel features.

Box 2. XSPRO for cross-sectional data

XSPRO is a USFS computer program designed for use by specialists and non-specialists alike to calculate hydraulic parameters based on cross-sectional surveys (Grant et al. 1992). The program accepts x- and y-coordinates from the cross-sectional survey along with depth of flow (either observed or inferred) and calculates a series of hydraulic parameters, including shear stress and stream power. The program produces both graphical and tabular outputs. XSPRO is available free of charge and is relatively easy to use. It is available from West Consultants at **http://www.westconsultants.com.**

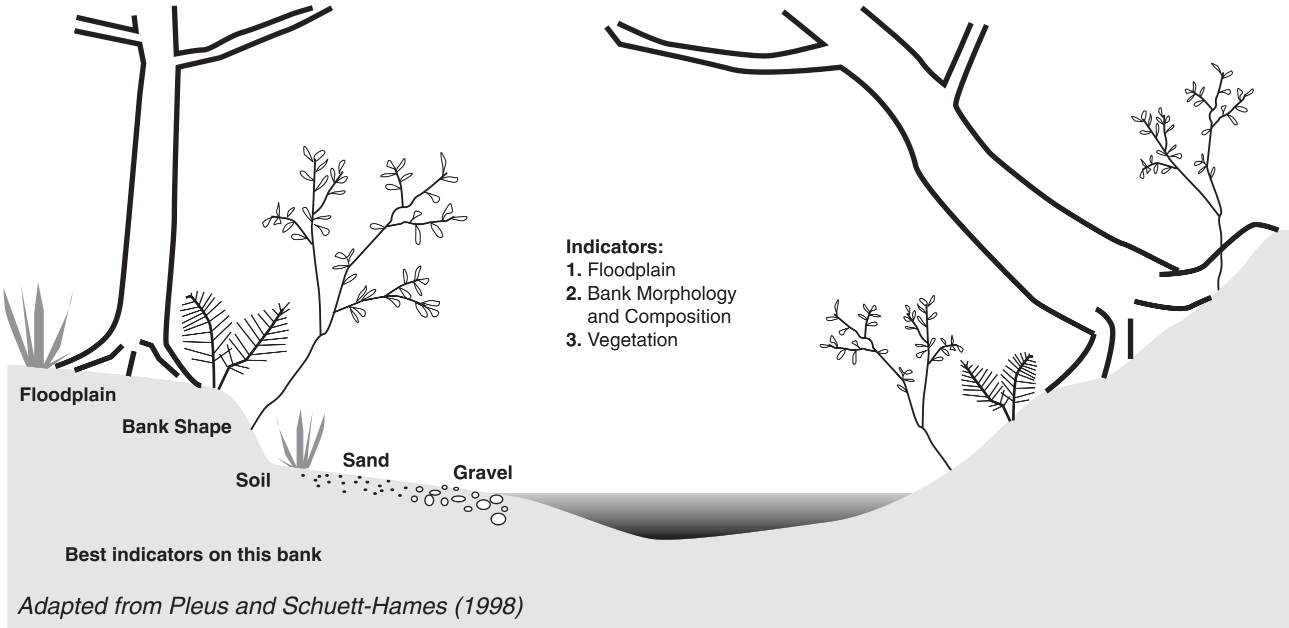
Channel width and depth

The most useful measure of channel width and depth is at bankfull flow because this discharge is morphologically definable in the field and typically has the greatest control on the dimensions of alluvial channels over time (Leopold et al. 1964). Bankfull flow is generally reached once every two years (Dunne and Leopold 1977). Bankfull width and depth refer to the width and average depth of the channel at bankfull flow. While the boundaries of the bankfull channel can be difficult to consistently identify, the edge of the bankfull channel usually corresponds to the start of the floodplain (Figure 8). The floodplain is defined as the generally flat landscape feature adjacent to most channels that is overflowed at times of high discharge (Dunne and Leopold 1977). The start of the floodplain is often characterized by the following features:

- A berm or other break in slope from the channel bank to a flat valley bottom, terrace, or bench.
- A change in vegetation from bare surfaces or annual water-tolerant species to perennial upland or water-tolerant shrubs and trees.
- A change in the size distribution of surface sediments (e.g., gravel to fine sand).

Bankfull width and depth data are necessary for analysis of channel characteristics including the cross-sectional area, width to depth ratio, bed shear, and stream power. Benson and Dalrymple (1967) describe measurement methods in more detail.

Figure 8. Indicators for determining bankfull width



Adapted from Pleus and Schuett-Hames (1998)

Hydraulic roughness

Hydraulic roughness is a critical part of basic hydraulic calculations because it addresses a loss of energy from turbulence. Less energy to move water and sediment has important implications for water discharge, sediment transport, and erosion rates. The elements of roughness, including particle size, form roughness (e.g., dunes and riffles), and vegetation roughness, can change under natural circumstances or by human intervention. Roughness due to vegetation may also change seasonally.

Manning's n is the most commonly used roughness parameter and is derived from Manning's Equation to calculate stream flow velocity:

$$V = (1/n)(R^{2/3})(S^{1/2})$$

Where: V = velocity (ms^{-1}), n = hydraulic roughness (dimensionless), R = hydraulic radius of the channel (the area of the channel divided by the length of the wetted perimeter) (m), and S = channel slope or gradient.

Manning's n cannot be directly measured but can be estimated if the other variables in the flow equation are known. Estimates of Manning's n have been developed for a broad range of natural and artificial channels. Tabulated values or photographs of representative stream reaches of known roughness can provide useful estimates of hydraulic roughness (Cowan 1956; Chow 1959; Barnes 1967). Estimates of hydraulic roughness on floodplains (Arcement and Schneider 1989) and in dryland streams (Aldridge and Garrett 1973) are also available to provide examples from different regions. Limerinos (1970) provides guidance on calculating roughness from field surveys of the channel bed.

Channel gradient

The gradient of the channel has a direct influence on the velocity of flow and the ability to entrain and carry sediment. The general channel gradient can be estimated from topographic maps, but local gradient changes will not be detected by this approach. Accurately measuring the gradient of the water surface (typically based on estimated bankfull elevation) with a level or transit is important for site-specific evaluations of stream discharge and sediment transport.

Substrate size and distribution

Determining the size and distribution of streambed substrate can provide information on roughness elements and aquatic habitat types. Streambed particle sizes can also be important for evaluating channel stability following disturbances (e.g., regulated dam releases or construction projects on the floodplain).

Classification of substrate type is an easy qualitative descriptor of the channel bed. Categories of substrate size typically include clay, silt, sand, gravel, cobble, and boulder (Table 2). Finer gradations of each particle size such as coarse, medium, or fine may be useful to provide greater detail on the substrate character.

Table 2. Substrate size categories

Substrate	Size Range (mm)
Clay	<0.0039
Silt	0.0039-0.0625
Sand	0.0625-2.0
Gravel	2.0-64.0
Cobble	64.0-256.0
Boulder	256.0-4096.0

Two quantitative methods for characterizing streambed particle size are sieve analysis and the relatively easy Wolman's method of pebble counts (Wolman 1954; Potyandy and Hardy 1994). For either method, a sample of particles is measured at cross-sections of the channel bed or bar. A sieve analysis simply involves filtering a sediment sample through various sieves to characterize the range of particle sizes. The Wolman pebble count relies on measurements from a sample of surface sediments. To create a representative sample, the median diameter of each particle touched by the toe of one foot is measured at every step or series of steps in several passes across the channel. A sample size of at least 100 particles is usually necessary to conduct simple statistical analyses. Reid and Dunne (1996) provide a more detailed discussion of the location and number of samples necessary to characterize substrate. With either method, a frequency distribution is usually created to identify the mean or median diameter (D_{50}) and the diameter at two standard deviations from the mean (D_{16} and D_{84}). Several cross-sections should be evaluated in a reach to determine the general character of the streambed. Harrelson et al. (1994) provides a good description of how to characterize bed and bank materials.

Quantitative analysis of cross-section data

Width to depth ratios

Monitoring changes in channel dimensions can be a useful method for identifying and evaluating trends in channel conditions. One of the simplest comparisons is a width to depth ratio. The depth can be either the average or maximum bankfull depth. Changes in the ratio over time or space are usually indicative of differences in water discharge or sediment transport capacity. Care must be taken to differentiate changes due to episodic events such as flooding from long-term watershed changes such as increased water or sediment supply from urbanization.

Water velocity and discharge

Calculating discharge is a function of the channel area and the velocity of the water. Stream discharge data can usually be obtained from the Hydrology module, although more site-specific estimates may be necessary for stream power and sediment transport analysis.

Hydrology

Locally developed empirical equations are a common tool for estimating discharge. Equations to estimate flood flows have been developed throughout the United States and are relatively easy to apply. Most equations are based on a regression analysis of existing discharge data and are generally a function of the basin area, precipitation, and vegetative cover. The length of streamflow records and the uniformity of the landscape are important to consider in evaluating the accuracy of these predictions.

More accurate site-specific discharge measurements can also be obtained from cross-sectional survey measurements. A number of software packages, such as XSPRO (Box 2), can be used to help estimate discharge using Manning's or other equations. More intensive field methods for calculating discharge generally fall into four categories:

- Volumetric measurement (generally appropriate only for small streams).
- Measurement of stream velocity and cross-sectional area.
- Dilution gauging using a salt or dye.
- Artificial controls such as weirs, with known stage-discharge relationships.

Further information on techniques for measuring velocity and stream discharge can be found in Corbett (1962) and Herschy (1985).

Stream power

Stream power is a measure of the stream's capacity to move sediment over time. Stream power can be used to evaluate the longitudinal profile, channel pattern, bed form development, and sediment transport of streams. It may be measured for an entire stream length or stream reach or per unit of channel bed area. The general form of the stream power equation is as follows:

$$\Omega = \rho g Q s$$

Where: Ω = stream power, ρ = density of water; g = gravitational acceleration; Q = water discharge; and s = slope.

A general evaluation of power for an entire stream or a particular reach can be calculated using the average discharge and average valley or channel slope for the given length. Measurements of stream power per unit of bed area provide a more accurate assessment of the stream's ability to move material because frictional losses of energy are accounted for in the equation.

In addition to measurements of discharge and channel slope at a cross-section, a measure of shear stress (τ) needs to be calculated. Shear stress may be described as the drag exerted by the flowing water on bed sediments and the channel perimeter. Shear stress is defined as follows:

$$\tau = \rho g R s$$

The actual amount of work accomplished by the stream per unit of bed area depends upon the available power divided by the resistance offered by the channel sediment, forms, and vegetation. The stream power equation can thus be rewritten as follows:

$$\omega = \rho gRsv = \tau v$$

Where: ω = stream power per unit of bed area and v = average water velocity.

Consult the reference books on channels listed at the beginning of the "Level 2 Assessment" section for further details on calculating stream power and shear stress.

Detailed Channel Classification

As discussed briefly in the Level 1 assessment section, numerous channel classification systems exist to characterize stream reaches. Classification systems are useful descriptors of stream behavior and can be applied for extrapolation and prediction. Thus, classification systems that are based on natural physical processes provide the greatest potential for accurate predictions. The simplest forms of channel classification rely on stream order (Strahler 1952) or plan form channel patterns such as sinuosity and braiding intensity (Brice 1960).

Several reviews of fluvial classification systems exist to help evaluate various approaches (Goodwin 1999; Thorne 1997; Downs 1995; Naiman et al. 1992). A brief list and description of reach-scale stream classification systems follows:

- Leopold and Wolman (1957): A simple three-part division of river patterns into braided, meandering, and straight.
- Kellerhals et al. (1976): A more complex system based on a combination of channel pattern, islands, channel bars, and major bedforms.
- Rosgen (1994): A hierarchical system with eight primary stream types based on dimensional properties of the channel.
- Woolfe and Balzary (1996): A process-oriented approach with eight categories that relate rates of aggradation/degradation for the channel and floodplain.
- Whiting and Bradley (1993): A process-oriented system, primarily applicable to headwater areas, with 42 stream classes based on dimensional measures of channel form.
- Montgomery and Buffington (1997): A probabilistic system with seven channel types based on dimensional and qualitative morphologic characteristics.
- Nanson and Croke (1992): A probabilistic classification of 15 floodplain types based on both process and form dimensions.
- Miall (1996): An example-based approach with three major classes divided into 16 fluvial styles that are derived from predominantly qualitative morphologic characteristics.

Sediment Budgets

A complete sediment budget considers the sources, storage, and transport of sediment from a watershed. As described in the Erosion module, evaluation of sediment sources to streams is often sufficient to evaluate the effects of land management activities. However, where it is important to understand the fate of sediment once it enters the stream channel, the storage and transport of sediment will need to be investigated.

The transport, deposition, and storage of sediment can be very complex, with impacts at sites far removed from the original sediment inputs. Prior to conducting a detailed analytical assessment, a qualitative evaluation of channel conditions from aerial photographs and field observations will help to focus the analysis on areas of the stream network that have been most responsive to changes in sediment or flow inputs. Depending on the identified watershed issues, it may also be possible to focus on just coarse or fine sediment yield and transport. Identifying trends in channel conditions and predicting channel response can often be accomplished by a combination of qualitative observations and quantitative analysis with an order of magnitude accuracy.

Erosion
Hydrology

Close interaction among the Channel, Erosion and Hydrology analysts will typically be required to develop a useful sediment budget. The Erosion module can provide qualitative information on geology/soil influences and quantitative estimates of sediment inputs. The Hydrology module can provide data on flood history and the factors that are influencing runoff and stream discharge. Collectively, this information will provide a good, semi-quantitative, systematic understanding of channel processes and sediment distribution patterns.

Sediment budgets are particularly useful for assessing water quality and morphologic channel changes due to altered inputs of sediment or water to streams (Reid and Dunne 1996). The evaluation of changes typically requires characterizing a channel under undisturbed conditions and predicting how those characteristics will change with alterations in sediment or water inputs. Table 3 provides examples of channel issues that can be evaluated with sediment budget techniques. Aerial photos, field surveys, substrate analysis techniques, and flow equations have been addressed in previous sections of this module. Sediment mobility analysis and sediment transport equations are discussed in the following sections.

Table 3. Examples of channel issues and selected techniques for evaluating changes in channel conditions (adapted from Reid and Dunne 1996).

Example Questions	Aerial Photos	Field Surveys	Flow Equations	Substrate Analysis	Transport Equations
How much introduced sediment will be transported out of the watershed?	▼	▼	▼	▼	▼
What proportion of introduced sediment be deposited and where will it be deposited?	▼	▼	▼	▼	▼
How will changes in sediment inputs affect channel form?		▼		▼	▼
How long will it take for the channel to recover from sediment inputs?			▼		▼
How will altered sediment inputs affect water quality?				▼	▼
Will a change in flow cause incision or aggradation?			▼	▼	▼
Where are incision or aggradation likely to occur?	▼	▼		▼	
How fast will a reservoir lose storage capacity?			▼	▼	▼

Sediment mobility analysis

Sediment transport is generally divided into two components: suspended load and bedload. The suspended load (or washload) is composed of sediment that is fine enough to be flushed downstream as part of the water column and that does not accumulate in significant quantities except where overbank flows deposit material on the floodplain. The bedload consists of the coarser sediment fraction that at least intermittently settles to the bed during its downstream migration. While a portion of the bedload is suspended at higher discharges, the distinction between bedload and washload is still appropriate for most situations during the dominant transporting flows.

Bed mobility analysis

The focus of most bed mobility analyses is on which grain sizes can be moved at which discharges. The traditional method for predicting the initial motion of a bed particle involves analyzing the effect of the shear stress from flow near the bed on the lift and drag forces that move a particle out from neighboring grains (Reid and Dunne 1996). This method, often referred to as Shields' function, yields the following equation for rough beds with turbulent flow:

$$\tau_C = \rho gds = 0.06(\rho - \rho_S)gD$$

> Where: τ_C = critical shear stress; ρ and ρ_S = the density of water and sediment, respectively; g = gravitational acceleration; d = flow depth; s = water slope; and D = the diameter of the particle of interest and its neighbors.

Graf (1971) and Richards (1990) provide a good review of the relationship between particle size and channel geometry, the combination of lift and drag forces, and the initiation of particle transport. Reid and Dunne (1996) provide a good summary of empirically derived equations from the scientific literature on initiation of motion for bed particles. Application of particle entrainment equations requires a strong background in fluvial geomorphology and understanding of the scientific literature.

Local field observations, however, can provide a general estimate of particle sizes that are transported during floods and can be a useful check of critical shear stress equations (Reid and Dunne 1996). Maximum mobile grain size can be estimated by measuring the largest particles that were obviously rearranged on gravel bars or that were deposited over new organic debris. Painted rocks and scour chains can also be used as part of a monitoring program to gather data on bed scour before and after floods.

Suspended load grain size estimates

Determining which particle sizes are suspended at various flows is often the first step in evaluating sediment transport rates. The magnitude of the settling or fall velocity reflects a balance between the downward force due to the particle's weight and opposing forces due to fluid viscosity and inertial effect. Viscous resistance is a dominant force for small particles in the silt-clay range but is less important for larger particles (Richards 1982). The suspendibility of a particle is usually defined as follows:

$$P < w_s / u^*$$

Where: w_s is the settling or fall velocity of the particle, and u^* is the shear velocity of the flow.

The settling velocity and shear velocity can be defined as follows:

$$w_s = 9000\ D^2 \quad \text{for silts and clays}$$

$$w_s = [0.67\ Dg\ (\rho-\rho_s)/r]^2 \quad \text{for sands and gravels}$$

$$u^* = (\tau/\rho)^{0.5}$$

Dietrich (1982) describes a method for estimating the settling velocity of natural particles. In the absence of good field data, Komar (1980) provides estimates for suspendibility based on a review of available data. Most of the data, however, were obtained from flume experiments or low-gradient, sand-bedded channels and may not be appropriate for some streams.

Sediment transport

Information on sediment transport rates can be useful for evaluating changes in land management or flow regimes and for identifying locations of potential aggradation or degradation. Suspended sediment transport can also be an important factor for evaluating pollutants because many contaminants move through the stream network attached to sediment rather than through solution (Horowitz 1991).

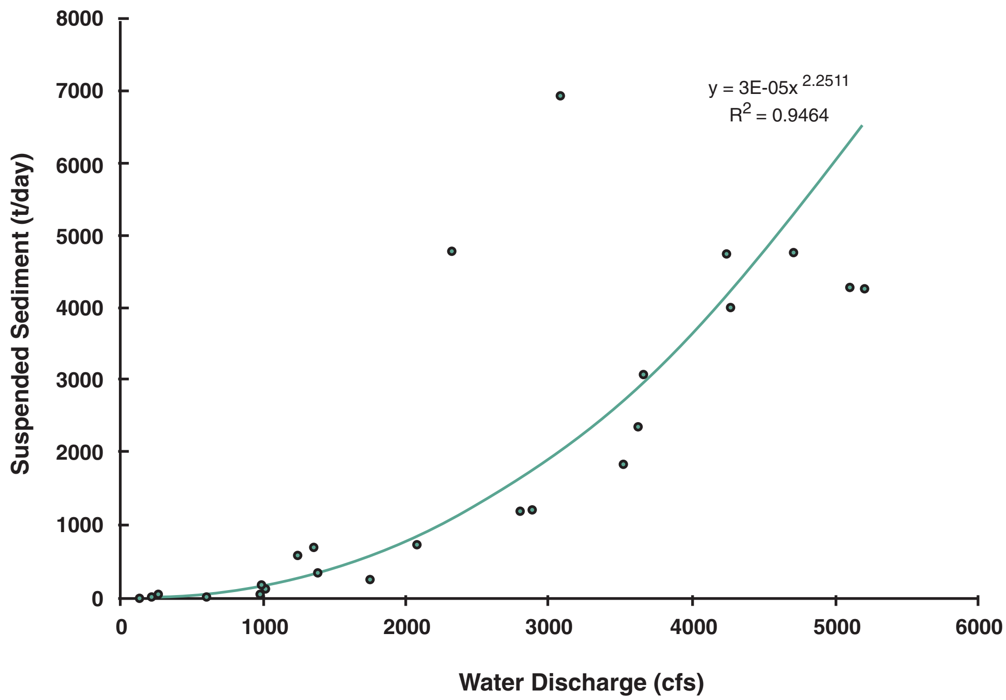
◄ Water Quality

Sediment transport rates can be characterized using any combination of field observations, monitoring data, and predictive equations. The following sections describe methods for determining sediment transport rates for both suspended load and bedload.

Suspended load

The suspended load often represents the majority of sediment transport but is difficult to predict because the transport rate depends more on sediment supply than on channel hydraulics (Reid and Dunne 1996). The primary method for evaluating suspended sediment transport rates requires data from a sediment sampling program. Suspended sediment concentrations can then be related to the stream discharge to provide an estimate of transport rates (Figure 9). Since most sediment transport occurs during floods, it is essential to have sampling data from periods of high discharge. The USGS publishes a great deal of suspended sediment and streamflow data, much of which is available at **http://webserver.cr.usgs.gov/sediment**.

Figure 9. The relationship between suspended sediment and discharge data, Newaukum River, Washington, 1964-1965



Long-term suspended load transport rates can also be estimated by comparing the grain size distribution of sediment inputs with the channel bed composition (Reid and Dunne 1996). The size fraction that is missing from the bed is considered the suspended load. Multiplying the sediment input rate by the proportion of the missing size fraction would then provide an estimate of the suspended load.

Bedload

While no definitive bedload transport equation exists, a number of different transport equations have been developed for sand- and gravel-bedded streams. Data requirements vary among equations, but most require information on channel gradient, depth, width, and sediment character. Graf (1971), Vanoni (1975), and Reid and Dunne (1996) review a number of sediment transport equations and provide further references for detailed application.

Most of the bedload transport equations have a strong empirical basis and are best suited for conditions similar to those used in the development of the equation. Moreover, most equations were developed from flume experiments and depend on a number of assumptions that may limit their extrapolation to natural stream environments. It may be useful to use a number of different equations to assess the accuracy of the estimates. A great deal of judgement and experience are necessary to use these types of equations and to make meaningful interpretations. Some field measurements may be necessary to verify calculated results.

Sediment storage

Sediment is stored in and released from channels and valley floors over time periods ranging from days to centuries. The accumulation of sediment may have important ecological implications and be a significant part of the sediment budget. Dietrich et al. (1982) provide an overview of sediment storage and estimate residence times for several types of storage reservoirs, including debris fans, active channel sediment, and floodplain sediment. Qualitative observations and analysis are often sufficient to assess the influence of sediment storage on the sediment budget. For example, observations or mapping of depositional forms and textures (e.g., gravel bars, floodplains) may be adequate to determine the locations and size fractions of sediment deposition in the watershed or whether sediment volume is increasing or decreasing.

Trends in aggradation and incision can be estimated from a number of field indicators, including changes in the riparian community, cross-sectional surveys at stream gage and bridge locations, or buried structures such as riparian trees, bridge piers, or fence posts. Studies that have evaluated sediment storage include the following:

- Trimble (1983) evaluates long-term alluvial storage in a Wisconsin basin.
- Kelsey et al. (1987) evaluate sediment reservoirs from a basin in northern California.
- Likens and Bilby (1982) address in-channel sediment and nutrient storage behind logs in New England streams.
- Laird and Harvey (1986) examine the effects of wildfire on aggradation and incision in Arizona streams.
- McGuiness et al. (1971) and Matherne and Prestegaard (1988) evaluate seasonal patterns in sediment storage for basins in Ohio and Pennsylvania, respectively.
- Collins and Dunne (1990) plot low-flow water elevations over time and use channel cross-section surveys at bridges to show changes in bed elevation from gravel mining.

Sediment detained by lakes or reservoirs also provides an opportunity to estimate sediment transport and storage. Griffen (1979) reviews methods for determining trap efficiencies in large reservoirs. Heinemann (1981), Moglen and McCuen (1988), and Dendy and Champion (1978) provide methods and data for evaluating the trap efficiency of small reservoirs and detention basins.

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Form C1. Historical channel changes

Channel segment(s)	Historical changes	Other observations

Form C2. Geomorphic channel type characteristics

Channel type	Description	Channel segments	Potential responsiveness rating			Evidence supporting rating
			Sediment	Runoff	Vegetation	

Erosion

Background and Objectives

The purpose of the Erosion module is to characterize the physical landscape of the watershed and assess its susceptibility to erosion from natural processes and land use practices. The primary product is a geomorphic land type map that categorizes areas based on topographic, geologic, and soil properties and identifies the erosion potential of each land type. Geomorphology is the study of landforms. It focuses on the processes that create landforms, such as rainfall and runoff, and the relation of geologic material to surface features (Dunne and Leopold 1977). Geomorphic information can be used to forecast the effects of different land use practices on the landscape.

The Level 1 procedure relies primarily on existing information about erosion in the watershed. Topography, soil, and geology maps are used to delineate land types based on physical landscape characteristics. The objective of a Level 1 assessment is to generally correlate erosion potential with various land types. Further evaluation and data collection in a Level 2 assessment are often necessary to validate land type erosion potentials.

Level 2 methods require expertise in evaluating geology, soils, and erosion processes. Erosion processes are evaluated in more detail, and the assessment typically involves field surveys. A greater effort is made to quantify sources of erosion from natural processes and land use activities.

Erosion Module Reference Table

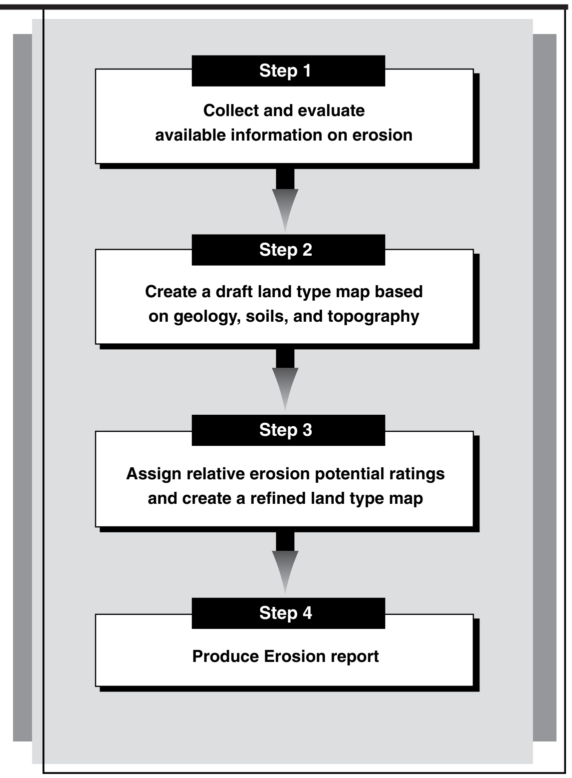
Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
E1: What and where are the dominant erosion processes in the watershed?	• Aerial photos • Soil surveys • Geology maps • Topography maps • Interviews (anecdotal information)	• Review of existing map and survey data • Erosion severity classification	• Detailed field review of erosion • Revised Universal Soil Loss Equation (RUSLE) • Water Erosion Prediction Procedure (WEPP)
E2: How do land use activities affect erosion processes?	• Aerial photos • Soil surveys • Topography maps • Interviews (anecdotal information)	• Review of existing map and survey data	• Detailed field review of erosion • RUSLE • WEPP
E3: What geomorphic land types exist in the watershed and where are they located?	• Aerial photos • Soil surveys • Geology maps • Topography maps	• Review of existing map and survey data • Land type classification	• Review of aerial photos • Field review of geomorphic land types
E4: Where and how much has soil compaction reduced the productivity of soil in the watershed?	• Soil characteristics • Road density data • Land use maps	• Estimate the amount and location of compacted areas • Review of existing soil map and survey data	• Current/historical aerial photo analysis • Field surveys to evaluate current soil compaction hazard
E5: How significant an erosion process are landslides in the watershed?	• Landslide rates • Landslide volumes • Aerial photos	• General landslide inventory	• Detailed landslide inventory • Field Surveys
E6: Is sheetwash erosion a significant source of sediment in the watershed?	• Soil characteristics • Precipitation data • Slope length and gradients • Vegetation cover • Land use maps • Interviews (anecdotal information)	• Review of existing soil map and survey data	• Field surveys to estimate annual erosion rates • RUSLE • WEPP
E7: Is erosion from roads or road management practices a significant source of sediment in the watershed?	• Road mileage • Percent stream delivery • Road characteristics • Aerial photos	• Inventory of general road characteristics • Determine frequency of stream/water crossings by roads	• Washington State Forest Road Erosion Model • USFS R1-R4 Forest Road Erosion Model • RUSLE
E8: Has natural wildfire or modern fire suppression had an influence on erosion in the watershed?	• Aerial photos • Vegetation maps		• Reconstruct fire history • Evaluate current and historical vegetation maps • Field surveys to evaluate erosion rates or fire frequency and intensity

Erosion Module Reference Table (continued)

Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
E9: Is gully erosion an important source of sediment in the watershed, and have erosion rates changed over time?	• Aerial photos • Anecdotal information • Soil maps and survey data	• Review of existing soil map and survey data	• Current and historical aerial photo analysis of gullies • Field surveys to estimate current annual erosion rate
E10: How significant a sediment source is streambank erosion in the watershed, and how have erosion rates changed over time?	• Aerial photos • Existing stream survey data • Anecdotal information		• Current and historical aerial photo analysis of bank erosion • Field surveys to evaluate current bank erosion rates
E11: Do other significant erosion processes occur in the watershed that have not been accounted for by other evaluations?	• Topography maps • Soil maps		• Wind erosion model • Field surveys to evaluate extent of dry ravel and soil creep
E12: What are the primary sources of sediment delivery to streams, lakes, wetlands, or other waterbodies in the watershed?	• Soil maps and survey data • Topography maps • Aerial photos		• Sediment budget • RUSLE • Soil creep estimation

Level 1 Assessment

Step Chart



Data Requirements

- Topographic maps
- Geology maps
- Soil maps
- Geomorphology or land type maps (if available)
- Slope class map (as necessary)
- Aerial photos (as necessary)

Products

- Form E1. Summary of erosion observations
- Form E2. Summary of land type characteristics
- Map E1. Land types
- Erosion report

Procedure

The focus of the Level 1 assessment is to evaluate the erosion potential of land types that occur in the watershed. Land types are areas with generally uniform characteristics and physical features (e.g., topography, soils) produced by natural processes. Even if erosion is not an issue in the watershed, determining land types may be a helpful exercise to understand other ecological characteristics such as vegetation communities or water quality. Consult with other module analysts early in the assessment to determine the level of detail and the scale of land type mapping that would be most helpful.

Step 1. Collect and evaluate available information on erosion

Collect anecdotal information

Consult people who are knowledgeable about soils, geology, or erosion processes and are familiar with the watershed to help identify the type and location of erosion problems. State natural resource departments or local agricultural offices often have experts familiar with local erosion problems. The NRCS, USFS, BLM, and USGS offices may also have resources available to evaluate erosion within the watershed. Another source of experts is a university or local college, where professors might have a great deal of knowledge about local erosion issues. Finally, local land managers may be knowledgeable about erosion in the watershed over time and the type of land use activities that have caused problems. Figure 1 summarizes the potential effects of land use activities on erosion processes and community resources.

Collect topography, geology, and soil maps

Topography, geology, and soil maps are important resources for evaluating the erosion potential in the watershed. USGS 7.5-minute topography maps are typically the most useful scale for evaluating erosion at a watershed scale. Topography maps can be used to identify steep slopes as well as slope shapes (e.g., concave, undulating, planar) with higher erosion potential. They can usually be obtained locally at map or outdoor recreation stores, or they can be ordered directly from the USGS.

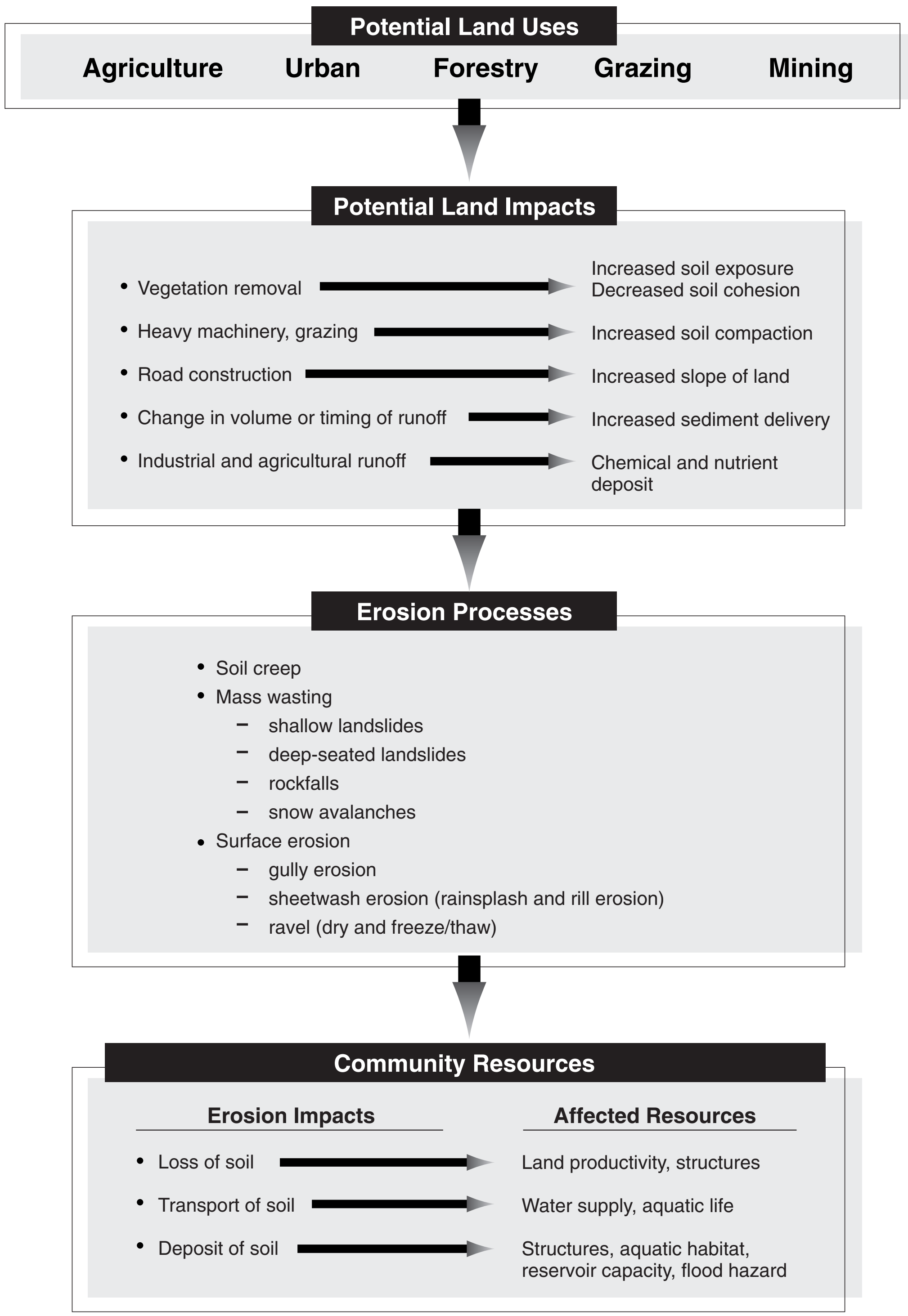
Geology and soil maps are often useful tools for evaluating baseline watershed conditions. Coordinate with the Channel, Vegetation, and Water Quality analysts to determine the type and scale of geology or soil information that would be most useful for evaluating differences in watershed conditions. USGS and state geology maps can provide helpful information on both bedrock and surficial geology. Some geologic formations may be naturally prone to erosion or be sensitive to land disturbance. These maps can be found at most university libraries, state geology departments, and USGS offices. Soil maps can provide important information about soil properties and may correlate well with specific land types. These maps can be found at most university libraries, state soil or agricultural offices, and NRCS offices. Both geology and soil maps are available as GIS overlays in many states.

Channel
Vegetation
Water Quality

Evaluate erosion information

Using information on topography, geology, and soils and anecdotal information on erosion problems, determine whether landslides, streambank slumping, and surface erosion are

Figure 1. Potential linkages between land use practices, erosion processes, and community resources



potentially active in the watershed and where they are potentially active. Aerial photos may be helpful in identifying larger areas with active erosion. If road erosion is a potential concern in the watershed, it may be helpful to gather information on road network characteristics, such as maintenance level, road density, and the frequency of stream/water crossings. Consult with the Aquatic Life and Channel analysts to determine the need for evaluating streambank erosion and the assessment detail. Form E1 (Figure 2) or a map that depicts similar information may be useful for summarizing observations and noting particular geologic formations or soil types that may be prone to erosion naturally or from management practices in the watershed.

Aquatic Life
Channel

Figure 2. Sample Form E1. Summary of erosion observations

Number	Erosion Feature	Location	Observations
1	Raw banks	Lower Silk Creek	Aerial photos and observations by tribal monitoring crew indicate unstable banks.
2	Sheetwash erosion	Road cuts on 60% slopes in the sandstone geology of Cispus River	Field investigation and county engineering reports indicate erosion problems on road cuts.
3	Gully erosion	Throughout the watershed on slopes > 30%	Aerial photos, field observation, and anecdotal information show gully erosion in the headwaters of most streams and below road drainage pipes.

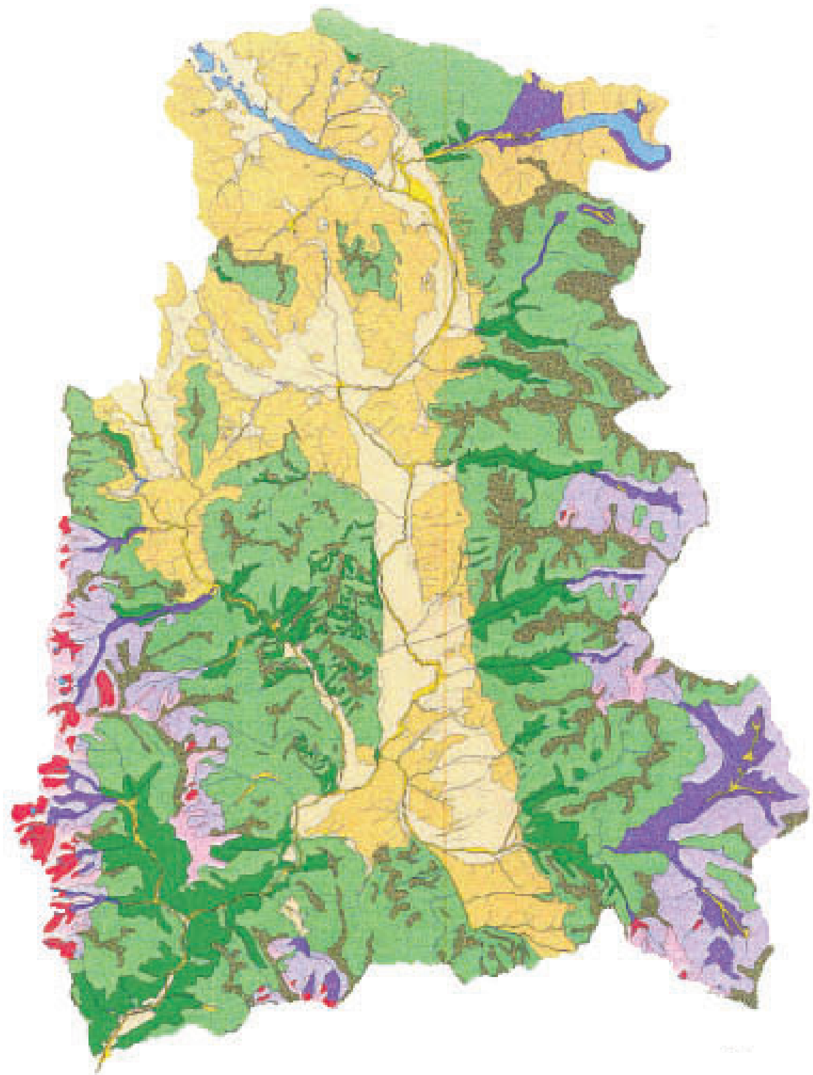
Step 2. Create a draft land type map based on geology, soils, and topography

Land types typically represent a feature with generally uniform shape and soil characteristics (Box 1). Land types should encompass the area created by a single geomorphic process (e.g., fluvial, glacial, colluvial, marine) with a set of characteristic features (Figure 3). For example, fluvial processes can create land types such as floodplain terraces, alluvial fans, and playas. Box 2 provides a list of commonly described geomorphic land types from across the United States. These land types are provided only as

Box 1. Penobscot Nation evaluation of land types

A geomorphic evaluation of the Penobscot River basin by the Penobscot Nation in Maine highlighted eskers as a land type with potentially important influence on Atlantic salmon habitat. Eskers are glacial outwash deposits from streams that flowed beneath the continental ice sheet and form narrow bands that generally parallel the Penobscot River. Where eskers cross the Penobscot River or its tributaries, gravel appears to be more prevalent and provides potentially important spawning habitat for salmon. Eskers may also be an important source of groundwater to streams to maintain cool water temperatures.

Figure 3. Landforms in the Thompson River basin, Montana



Note: Hydrology from 1:24,000 scale USFS Cartographic Feature Files Landtype Associations compiled from Lolo and Kootenai National Forest landtype mapping and from NRCS soil mapping.

examples, and the Erosion analyst will need to create land type descriptions best suited to the watershed. Two publications that may be helpful are Ritter et al. (1995), which provides a good summary of geomorphic processes that shape landscapes, and Haskins et al. (1998), which describes a geomorphic classification system.

Box 2. Examples of geomorphic land types from across the United States

Alluvial fan	Kettle outwash plains
Arroyos	Landslide deposit
Alpine glaciated basin	Loess deposit
Avalanche-prone hillslopes	Marine terrace
Badlands	Mesas
Backshore terrace	Piedmont
Basin floor depressions	Plateau
Canyonlands	Playa
Chenier plain	Prairie potholes
Cliffs	Rockland
Coastal marshlands	Slough bottomlands
Dissected planar slopes	Talus
Esker	Tidal mudflats
Floodplain terrace	Till plain
Glacial moraine	Valley flat
Glacial outwash terrace	Valley headwall
Karst limestone topography	Wet meadows

A watershed can have a large range of land types depending on the scale of assessment. Since no strict criteria exist for defining land types, the scale of assessment should be determined by the objectives of the Erosion assessment. In general, a finer scale (e.g., swales > 40% slope) will be most useful for addressing specific land management activities, while a broader scale (e.g., glaciated uplands) may be more helpful for quantifying general erosion rates. Consult with other module analysts to help determine the best assessment scale. In particular, coordinate with the Channel analyst, who will be identifying channel types based on geomorphic characteristics similar to land types.

Channel ▶

Geologic maps are often useful for identifying land types at a broad scale. Soil surveys typically provide information at finer scales and can be particularly helpful in identifying land types near streams and rivers. Figure 4 shows examples of soil association patterns. The correlation of soil types and geomorphology is commonly described in soil surveys. Soil types can be used individually or in aggregate to describe a land type. Geology and soil information may also be available as GIS overlays complete with erosion potential ratings. Erosion potential or erosion hazard ratings should be examined using the available data to evaluate their accuracy and applicability to the watershed.

Land types can be further refined using modifiers such as slope gradient, slope position, slope shape, and dissection frequency or pattern (Box 3). These land type modifiers can help focus the analysis on specific areas where erosion is most problematic. In some

Figure 4a. Correlation between soil types and geomorphology in Maine

Note that the Colton soils correlate directly with the eskers land type.

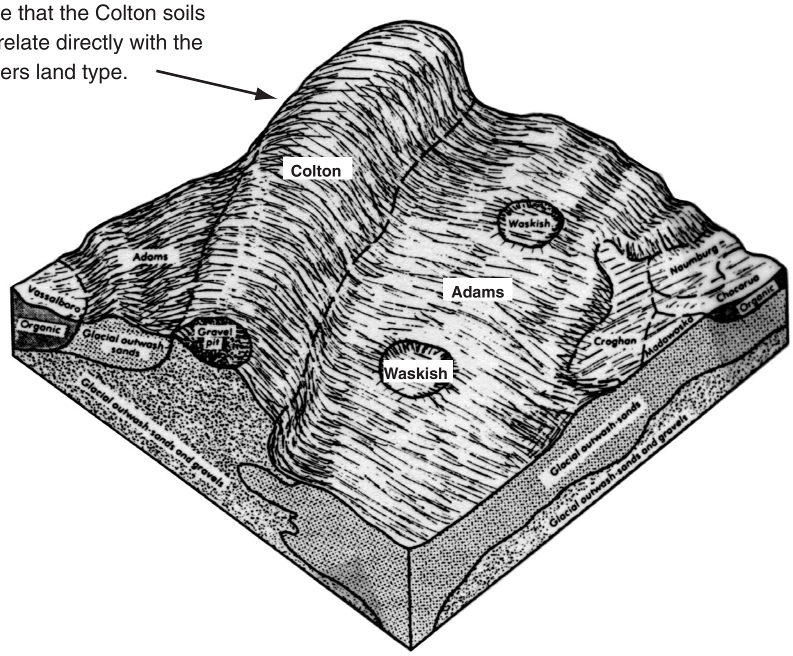
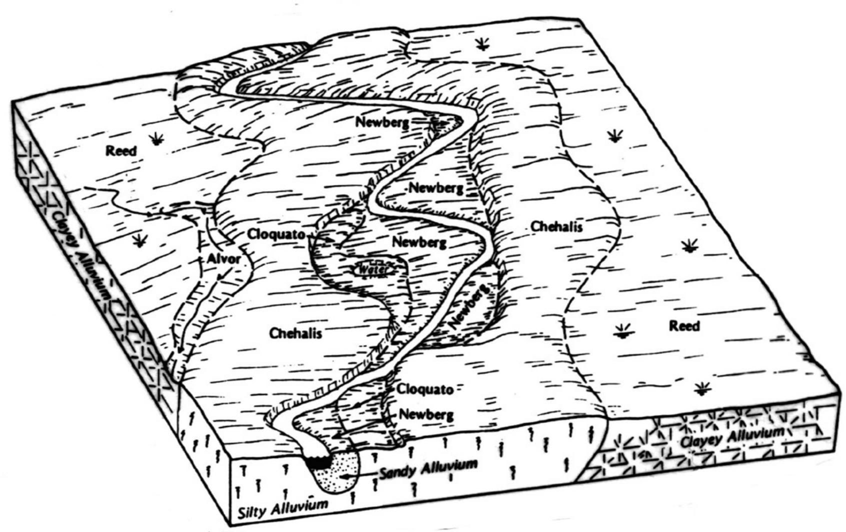


Figure 4b. Correlation between soil types and geomorphology in Washington State



Box 3. Slope class maps

Since slope gradient is often a primary factor influencing erosion potential, it may be useful to divide the watershed into similar slope classes. The increment used for slope classes will depend on the total relief of the watershed. Relatively low-relief watersheds typically will have slope class increments of 1-5 percent, while high relief watersheds may have increments of 5-20 percent. GIS programs can be used to efficiently create this type of map.

cases, it may also be useful to consider other ecological factors such as vegetation, climate, or aspect to help differentiate land types. Where possible, land types should be differentiated based on natural processes and not changes due to land use.

Step 3. Assign relative erosion potential ratings and create a refined land type map

Correlate the land types with information on erosion in the watershed. If a GIS system is available, it may be useful to overlay geology or soils maps with land use activities to highlight potential erosion concerns. It may be necessary to modify land type boundaries or develop new land types to best distinguish specific areas susceptible to erosion problems. Create a final land type map (Map E1) to use during the Synthesis process. Assign relative erosion potential ratings to each land type based on its susceptibility to mass wasting and surface erosion. It is important to remember that the erosion potential ratings in all but the most obvious cases will be hypotheses requiring additional information and further evaluation. Summarize information for each land type in Form E2.

Step 4. Produce Erosion report

The Erosion report should summarize geologic and soil characteristics, erosion processes in the watershed, and land management effects on erosion. The report will typically include the following components:

1. Site Description
   - Geology
   - Soil types
   - Topography
   - Erosion processes

2. Assessment methodology
   - Materials (e.g., aerial photo series and source)
   - Survey methods
   - Assumptions
3. Results of the assessment
   - Form E1. Summary of Erosion observations
   - Form E2. Summary of land type characteristics
   - Map E1. Land types
4. Conclusions
   - Erosion trends
   - Land management effects
   - Further data and assessment needs
   - Confidence in assessment
5. References

Level 2 Assessment

The organization of this section generally corresponds to the critical questions listed in the Erosion Module Reference Table. Most of the critical questions relate to a specific topic that can be evaluated using a number of methods or tools. For each topic, a general description of methods, guidance on the appropriate use of methods, and the expertise and time-frame required to complete the assessment are provided. Suggested references are also provided for more detail on available data, methods, and tools.

Soil Compaction

Soil compaction is typically caused by either the use of heavy machinery, such as for building construction and ground-based logging, or trampling due to animal grazing or by people, such as at heavily used recreation areas. Soil compaction may be a concern because of reduced water infiltration or reduced soil productivity for vegetation growth.

The sensitivity of soil to compaction is largely a function of soil texture. Soil texture is the relative proportion of sand, silt, and clay particles in a mass of soil. Soil with a high percentage of clay may be easily compressed. On the other hand, soil with a high percentage of sand cannot be easily compressed; thus it maintains its structure under heavy loads.

The primary method for evaluating large-scale soil compaction from urbanization, roads, and grazing is examining aerial photos. Land use maps may also provide useful information, although it may not be as accurate as information from a photo survey. To evaluate small-scale soil compaction and the degree of compaction, field surveys will be necessary. Soil compaction testers or penetrometers can be used to gather data on the compressive strength of the soil. Soil compaction from grazing or camping may only be a problem in isolated areas, such as near streams or lakes. It may also be possible to correlate field observations of compaction with specific soil types to help predict the potential for future compaction problems. Measuring and evaluating soil compaction can be easily done without extensive training, although a soil scientist may be needed for more intensive evaluations.

Landslides

Landslide evaluation on a watershed scale typically involves aerial photo analysis and creation of a landslide inventory. Typically, 1:25,000-scale or finer aerial photos are needed to accurately identify landslides. Orthophotos, if available, can be an important aid to transfer data from aerial photos to topographic maps. The landslide inventory should cover the longest period of record possible by using the oldest aerial photos through the most current photos. A long aerial photo record is important for evaluating the rate of rapid failures, such as debris flows and rockslides because of their episodic occurrence from infrequent large storms, and the movement rate of slumps and earthflows that may progress intermittently over months to centuries.

A comprehensive landslide inventory can be used to collect data that relate important variables to the risk of occurrence. A landslide inventory can include data on location (e.g., township, range, and section number), year of occurrence, type of landslide, hillslope gradient, parent material, slope form, soil type, land use trigger, or sediment delivery to a stream (Figure 5).

Figure 5. Sample landslide inventory form

Site #	Location	Year	Type	Gradient (%)	Trigger	Stream Delivery
1	21N, 15E Sec. 2	1968	Shallow rapid	70-80	Road	Yes
2	20N, 13E Sec. 31	1993	Deep-seated	30	Natural	No
3	21N, 12E Sec. 11	1951	Rockfall	60	Natural	No

Some training and experience are necessary to accurately identify landslides on aerial photos, particularly for older, inactive, or deep-seated landslides. Some field measurements may also be necessary to estimate the minimum identifiable size of landslide observable on aerial photos, landslide volumes, the frequency of smaller slides, and the frequency of slides hidden under forest canopy (Reid and Dunne 1996). Uncertainties in the aerial photo interpretation may be related to the following:

- Physical conditions that contributed to the landslide.
- Land use trigger mechanisms.
- Delivery of sediment to public resources.
- Extrapolation from areas of known hazard to areas of unknown hazard.

Further information on creating landslide inventories can be found in Sidle et al. (1985), the federal guide for watershed analysis (RIEC and IAC 1995), the Washington State watershed analysis manual (WFPB 1997), and the Oregon watershed assessment manual (Watershed Professionals Network 1999). NCASI (1985) contains data from landslide inventories in the Pacific Northwest.

Sheetwash Erosion

Sheetwash erosion is movement of soil particles caused by rainsplash and rill erosion. Sheetwash erosion occurs naturally in areas with generally sparse vegetation or after wildfire but can also be prevalent in agricultural croplands and rangelands.

Table 1 contains the results of soil loss measurements from hillside plots around North America under different land use conditions. These data can be used to derive a crude but quick estimate of erosion in a watershed. It is important to note that these soil loss estimates do not address sediment delivery to streams. Sediment delivery distances need to be estimated along with average soil loss to evaluate sheetwash erosion impacts to streams.

Revised Universal Soil Loss Equation

The most commonly used model to predict sheetwash erosion under various land uses is the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997). The publication by Renard et al. (1997) should be consulted for more detailed information and application of the RUSLE. Use of this model typically requires some expertise and familiarity with conducting erosion studies. A GIS system is also very helpful for simplifying many of the steps.

The RUSLE is best used for agricultural lands in the central and eastern United States, although refinements in values and additional data from the western United States allow its use in most agricultural areas (Renard et al. 1997). The latest version of the RUSLE (Renard et al. 1997) replaces previous versions published by the USDA.

Table 1. Measurements of soil loss from hillside plots

Land Use	Location	Soil Loss (tons/acre/yr)	Source
Forest			
Primeval	Oklahoma	0.01	Smith and Stamey (1965)
Burned annually	Oklahoma	0.11	Smith and Stamey (1965)
Primeval	North Carolina	0.002	Smith and Stamey (1965)
Burned semiannually	North Carolina	3.08	Smith and Stamey (1965)
Woodland, protected	Texas	0.05	Smith and Stamey (1965)
Woodland, burned annually	Texas	0.36	Smith and Stamey (1965)
Woodland, protected	Ohio	0.01	Smith and Stamey (1965)
Woodland, protected	North Carolina	0.08	
Agriculture, Cultivated Grasslands			
Bluegrass	Midwestern U.S.	0.02-0.34	Smith and Stamey (1965)
Alfalfa	Midwestern U.S.	0.03-0.15	Smith and Stamey (1965)
Clover and grass	Virginia	0.01-0.07	Smith and Stamey (1965)
Bermuda grass	Southwest U.S.	0.00-0.10	Smith and Stamey (1965)
Fescue grass	Georgia	0.20	
Hayland	Washington	0.01-0.08	Smith and Stamey (1965)
Hayland	North Carolina	0.31	Smith and Stamey (1965)
Tropical perennial grasses	Puerto Rico	1.2	Smith and Stamey (1965)
Tropical kudzu	Puerto Rico	0.18	Smith and Stamey (1965)
Agriculture, Croplands			
Bare fallow	Georgia	100	Barnett (1965)
Bare fallow	Midwestern U.S.	69	Bennet (1939)
Corn	Midwestern U.S.	17.86	Jamison et al. (1968)
Corn	Midwestern U.S.	73.2	Bennet (1939)
Rangeland			
Dry woodland and rangeland	Southern California	2.7	Krammes (1960)
Dry woodland and rangeland, after fire	Southern California	24.7	Krammes (1960)
Dry woodland and rangeland	New Mexico	21.2	Leopold et al. (1966)
Sparse grassland	Alberta	7.7	Campbell (1970)
Urban			
Road cuts	Georgia	79-237	Diseker and Richardson (1961)
Building sites	Maryland	125-219	Wolman and Schick (1967)
Building sites	Maryland	189	Guy (1965)
Mining			
Land devegetated by smelter fumes	Ontario	26.1	Pearce (1973)
Spoil bank	Ohio	87	Geotimes (1971, Dec)
Rural Roads			
Forest roads	Idaho	29.7	Megahan and Kidd (1972)
Forest roads	Idaho	7.9	Copeland (1965)

Adapted from Dunne and Leopold (1977)

The RUSLE is as follows:

$$A = R*K*L*S*C*P$$

Where: A = Soil loss (tons/acre)
R = Rainfall erosivity index
K = Soil erodibility factor
L = Hillslope-length factor
S = Hillslope-slope factor
C = Cropping management factor
P = Erosion control practice factor

The rainfall erosivity index (R) corresponds to the average annual energy and intensity of rainstorms and has been mapped across the United States. The soil erodibility factor (K) is the average soil loss at a specific rainfall erosivity when the soil is exposed as cultivated bare fallow. The soil erodibility factor has also been calculated for different soils across the country and is listed in most NRCS (formerly the SCS) soil surveys. The effect of topography is accounted for by the hillslope-length (L) and hillslope-slope (S) factors. Hillslope-slope factors can be estimated in the field using inclinometers or levels or in the office using topographic maps (maps with 2-foot contour intervals are recommended). Topographic factors for uniform hillslopes under various land use conditions, such as cropland, rangeland, or construction sites are listed in Renard et al. (1997). The cropping management factor (C) and the erosion control practice factor (P) account for vegetative cover and soil tillage practices, respectively. Tables with a range of factors, as well as more detailed assessments for site-specific determinations of both C and P, can be found in Renard et al. (1997).

The RUSLE is best used on smaller drainage basins by dividing the basin into areas of uniform soil type, topography, and agronomic conditions. The soil loss can then be computed for each combination. This exercise is greatly simplified if GIS can be used.

The RUSLE predicts the amount of soil moved from its original position and does not necessarily predict the amount of sediment transported out of an area or watershed. The delivery of sediment into streams or other sediment-transport conduits (e.g., gullies, ditches, canals) must be considered as a separate step. Ebisemiju (1990) found that sediment delivery was correlated with hillslope gradient and infiltration rates on bare soils but was best predicted by slope length and soil erodibility on vegetated surfaces. If redeposited sediment is observed during field work, its relation to factors such as gradient, surface roughness, vegetation cover, storm runoff, and distance from the sediment source should be noted to identify the conditions under which delivery may be significant (Reid and Dunne 1996).

Water Erosion Prediction Procedure

The Water Erosion Prediction Procedure (WEPP) is now being developed to take the place of the RUSLE (Nearing et al. 1989). WEPP is designed to be more process-based and have wider applicability to cropland, rangeland, and forestland. Independent versions are being developed for hillslopes, small watersheds, and GIS-based grid cells. Both the hillslope and small watershed versions are expected to be PC-based expert programs (Reid and Dunne 1996). Contact the NRCS for further information about the availability of WEPP.

Road Erosion

Road surface erosion is generally evaluated separately from sheetwash erosion because of its wide distribution and importance (Reid and Dunne 1996). A number of factors can affect the production of sediment from roads, including surfacing material, traffic levels, rainfall, and drainage design. Road erosion is typically of greatest concern at stream crossings, although roads parallel to streams can also cause sedimentation problems.

Watershed-scale road erosion is typically evaluated by developing an average annual rate of erosion multiplied by the area of road delivering directly to waterbodies. Erosion rates from forest roads have been calculated for a number of regions of the country. Regional examples of forest road erosion data and empirically-based road erosion models include the following:

- Appalachian forest road data (Kochenderfer and Helvey 1984, 1987; Swift 1984).
- Pacific Northwest road data (Reid and Dunne 1984; Bilby et al. 1989) and watershed analysis road erosion model (WFPB 1997).
- Interior West road data (Megahan and Kidd 1972; Burroughs and King 1989) and R1-R4 model (Reinig et al. 1991; Ketcheson et al. 1999).

The previously discussed RUSLE and WEPP models can also be adapted to estimate road surface erosion.

Gully Erosion

Gully erosion can often occur in response to roads, grazing, or agricultural impacts in fine-grained, cohesive soils. Evaluating gully erosion typically involves aerial photo and field surveys to estimate the distribution and density of gullies and to determine an average annual rate of incision.

Gully widths can often be translated into volumes by using field measurements to relate width and cross-sectional area. The SCS (1977) found that widths of active gullies are typically about 3 times their depth in cohesive soils but only 1.75 times their depth in non-cohesive soils. This report also provides equations for predicting future rates of gully head retreat based on drainage area and rainfall intensities. With any equation or predictive model, it is important to evaluate its assumptions and make sure they are applicable to the watershed being investigated. Field evidence can be used to verify retreat rates by noting when particular structures, trees, fences, and roads are affected by the gully. Cooke and Reeves (1976) used this type of field evidence to track arroyo networks in the southwestern United States.

Streambank Erosion

The rate of streambank erosion can depend on a number of factors, including flood discharge, previous precipitation, bank material, and vegetation. Bank erosion along large streams can typically be observed on sequential aerial photos. The average rate of lateral retreat together with field measurements of bank height can be used to estimate sediment production rates. Examples of studies that have examined bank erosion in different parts of the United States include the following:

- California (Lehre 1982).
- Ontario, Canada (Dickinson et al. 1989).
- Utah (La Marche 1966).

The Channel module may also gather information on streambank erosion, so it is important to coordinate activities.

Channel ▶

Other Erosion Processes–Soil Creep, Dry Ravel, and Wind Erosion

Soil creep is the slow downhill movement of the soil mantle that results from disturbance of the soil by freeze/thaw processes, wetting or drying, or plastic deformation under the soil's own weight (Dunne and Leopold 1977). Other soil displacing processes such as tree throw and biological activity are typically included in estimates of soil creep.

Measured soil creep rates typically range from 0.001 to 0.002 m per year in the United States. Saunders and Young (1983) contains a compilation of measured rates of soil creep and other surface erosion processes from around the world. Soil creep rates may be higher in areas of clay-rich soil and in areas with active earthflow movement. Local soil creep rate data may also be available from a monitoring program.

Soil creep rates are often used to estimate bank erosion of colluvial material. Colluvium is the soil and rock debris on a hillslope that has been transported from its original location. This type of bank erosion generally occurs in small streams that are tightly confined. Soil creep supplies sediment to the bank, and the rate of sediment supply to the bank is assumed to be equal to the rate of bank erosion. Further detail on assessment of soil creep is provided in the next section.

Dry ravel is most prevalent on steep, sparsely vegetated slopes. Ravel is capable of moving larger particles than sheetwash erosion, and the sediment tends to accumulate in small talus cones and sediment fans (Reid and Dunne 1996). Ravel rates are typically highest during freeze/thaw and wet/dry periods, after fires that have consumed fallen logs and other organic debris on hillslopes, or on near-vertical streambanks and roadcuts. Exposure of tree roots and accumulation of sediments can be evaluated in field surveys to estimate rates of dry ravel (Megahan et al. 1983; Reid and Dunne 1984; Reid 1989).

Since wind erosion does not supply sediment preferentially to streams, sediment production from this source is often ignored. If necessary, input rates can be estimated by assuming channel inputs are proportional to the fraction of the land surface occupied by channels and ponds (Reid and Dunne 1996).

Evaluation of Watershed-Scale Sources of Erosion

A sediment budget is a tool used to determine the relative sources of sediment from various erosion processes, natural and management-related. A complete sediment budget considers the sources and storage of sediment and the export of sediment from the watershed. While the method is generally quantitative, the estimates are considered order-of-magnitude values. Sediment budgets that focus on the sources and relative contribution of sediment to channels can be useful for comparing natural sources of sediment (soil creep, fires, natural mass wasting, etc.) with management-related sources of sediment (e.g., erosion from agriculture, forest roads, urban construction sites, grazing). The relative differences can be used to better judge the impacts of changes in land use and to help focus efforts for improved management.

These methods typically require expertise in evaluating watershed-scale erosion and experience developing sediment budgets. Reid and Dunne (1996) and Swanson (1983) provide more detailed descriptions and examples of sediment budgets. Constructing a sediment budget will require coordination with the Channel analyst to address sediment transport and storage issues.

Channel ▶

Two approaches to estimating natural sediment production are discussed in this section: the soil creep model and the empirical sediment yield approach. The soil creep model is best used in watersheds with high topographic relief and a relatively small amount of alluvial bank cutting and when sediment yield data from the watershed or other nearby comparable watersheds are sparse. The empirical sediment yield approach relies on available data (typically from the USGS), generally collected on larger rivers, and can be used for most watershed types. If data on sediment yield are available and the soil creep model seems appropriate for the watershed, both methods should be used to get an idea of the range of error in the estimates. Both approaches are best at predicting the amount of finer sediment (sand-sized and smaller) exported from a watershed and may not capture bedload movement of larger particle sizes.

Soil creep model

The soil creep model provides an estimate of sediment yield from colluvial hillslope sources. Watershed sediment yield can be calculated using the following equation:

$$SY = C*2*L*D*SD$$

Where: SY = Sediment yield (tonnes/yr)
C = Creep rate (m/yr)
L = Length of stream (m)
D = Average soil depth (m)
SD = Average bulk density of soil (tonnes/m^3)

The creep rate is multiplied by the total stream length times 2 to account for creep on both sides of the channel. Stream lengths can be easily calculated using GIS, but the level of accuracy may need to be verified. Small streams may not be mapped and may constitute a large proportion of the stream network. Average soil depths can be estimated using soil survey information for the watershed. If soil depth varies significantly across the watershed, it may be necessary to break up the watershed into areas of uniform soil depth and then calculate erosion rates for each area. The bulk density of soil typically ranges from 1.2 to 1.7 tonnes/m^3 (SCS 1986). In the absence of watershed or regional data, an average bulk density of 1.5 tonnes/m^3 is typically used.

Empirical sediment yield approach

Channel

Where available, sediment yield data can provide accurate estimates of sediment production from watersheds. The USGS typically collects these data for watersheds around the country, but other sources may be available as well (Larsen and Sidle 1980; Dendy and Champion 1978). The sediment yield data should extend at least a few years and should especially cover times of higher streamflow, when the majority of sediment is transported. If these data are to be used as estimates of natural sediment production, the history of land use during the period of record should also be investigated. Where extensive land use practices have potentially increased erosion during the period of sediment yield data collection, the background rate can be back-calculated using information on management-related sources of sediment.

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Form E1. Summary of erosion observations

Number	Erosion Feature	Location	Observations

Form E2. Summary of land type characteristics

Land Type	Land Type Description	Total Area	Percent of Watershed Area	Mass Wasting Rating	Surface Erosion Rating	Observations

Vegetation

Background and Objectives

Vegetation is an important landscape element in any watershed. The distribution of vegetation species may be diverse and highly variable across the watershed, but vegetation communities can be described in more general terms as well. The vegetation module is designed to distinguish the primary plant communities and identify their distribution within the watershed. Because vegetation that grows along streams and other waterways is often quite different from upland vegetation in terms of composition and degree of interaction with aquatic processes, vegetation communities in the three environments (i.e., upland, riparian, and wetland) are characterized separately (Box 1).

Box 1. What and where is riparian vegetation?

Riparian vegetation consists of plants within the zone of direct interaction between terrestrial and aquatic environments (Swanson et al. 1982).

The riparian zone can be defined as the area where 1) vegetation growth is influenced by moisture from the waterbody (e.g., wetland or floodplain area), or 2) vegetation exerts a direct effect upon aquatic conditions (e.g., contributes shade or leaf litter).

Because determining which vegetation exerts a direct effect on aquatic conditions is a complicated task, the analyst will probably need to make some simplifying assumptions. A reasonable starting point to determine the area of riparian influence is to include all vegetation that is influenced by the waterbody (#1 above) plus an additional width equivalent to the height of the tallest plants. If using remote information such as aerial photos, the analyst will probably need to identify a fixed evaluation width along channels.

In most watersheds, the greatest portion of the total land area consists of uplands. Despite the distance from any waterbodies, upland vegetation exerts important influences upon various watershed processes. For example, upland vegetation may 1) produce leaf litter that affects erosion, 2) modify precipitation inputs through canopy interception, or 3) influence groundwater chemistry through plant decomposition. Although the total area situated along streams and wetlands is normally much smaller, the vegetation in these areas has a more direct effect upon aquatic conditions, providing such functions as shade, streambank reinforcement, and organic litter inputs, among other functions.

The primary focus of the Level 1 Vegetation assessment is to identify the primary vegetation types and plot their distribution across the watershed. The assessment methods rely largely upon interpretation of remote information, such as vegetation maps, aerial photos, or satellite images. While the analyst is examining and categorizing vegetation types, land use impacts may become apparent as well.

It is important to realize that vegetation communities are dynamic due to natural plant succession as well as human-caused and natural disturbances. It may take some skill to evaluate past or potential plant community composition based on a remote assessment of existing conditions. The assessment of specific changes in vegetation functions, as well as their causes, will benefit from close coordination with other members of the assessment team. In addition, the analyst may gain a preliminary sense of which functions the various vegetation types will provide most effectively. However, a determination of the relationship between vegetation function and specific land use impacts will require further consideration via a Level 2 assessment. The following are examples of analyses that would be performed in a Level 2 assessment:

- Assessing vegetation status to finer attributes (e.g., distinguishing tree size or density) or at finer scales of spatial resolution such as the “site” scale (i.e., < $1 mi^2$ or 1.0 mi of stream length).
- Assessing historical or potential vegetation conditions in detail.
- Assessing the specific land use practices that have created impacts (e.g., refining focus from “logging” to “tractor logging within 200 feet of streams”).
- Assessing the effectiveness of various vegetation types or conditions at providing individual functions.
- Assessing changes in aquatic resources that have resulted from vegetation changes.

Vegetation Module Reference Table

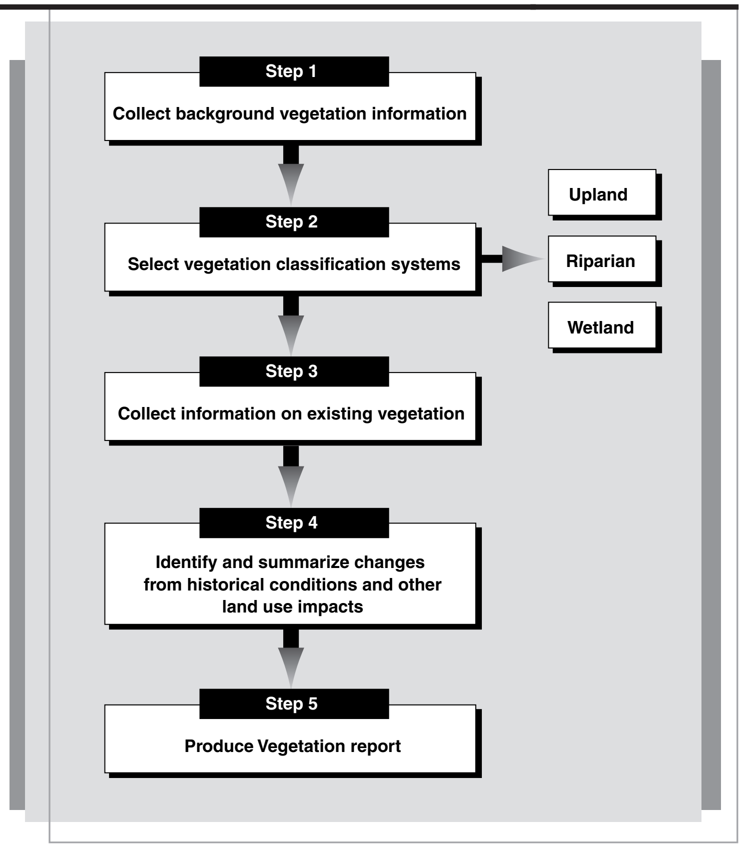
Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
V1: What are the primary vegetation categories that exist in upland areas?	• Previous vegetation studies • Vegetation maps, GIS data, aerial photos • Anecdotal information	• Prepare upland vegetation map from existing data and aerial photos (reconnaissance level)	• Refine upland vegetation map with further remote or field investigation • Focused assessment of special upland plant species or communities
V2: What are the primary vegetation categories that exist in riparian areas?	• Same as for V1 • Floodplain surveys • Local "sensitive" or "critical areas" inventories	• Prepare riparian/wetland vegetation map from existing data and aerial photos (reconnaissance level)	• Refine riparian/wetland vegetation map with further remote or field investigation • Focused assessment of special riparian plant species or communities
V3: What are the primary vegetation categories that exist in wetland areas?	• Same as for V1 • NWI maps • Soil surveys and hydric soils lists • Recent wetland delineations or assessments • Local sensitive or critical areas inventories	• Prepare riparian/wetland vegetation map from existing data and aerial photos (reconnaissance level)	• Refine riparian/wetland vegetation map with further remote or field investigation • Focused assessment of special wetland plant species or communities
V4: Does existing upland, riparian, or wetland vegetation differ substantially from historical conditions?	• Same as for V1-V3 for present conditions • Land use map • Historical vegetation maps • Old aerial or oblique photos • Old timber or stream survey narratives	• Document location and approximate extent of changes identified from remote or historical sources (reconnaissance level)	• Quantitative assessment of historical change that evaluates the area of vegetation involved and change in functional effectiveness • Reconstruct natural vegetation disturbance history: - flooding - wildfire - windthrow - avalanche - drought
V5: What are important functions of upland vegetation relative to watershed processes?	• Upland vegetation map prepared for V1 • Anecdotal information	• Develop preliminary list of upland vegetation functions	• Numerous methods depending on upland function; coordinate with other analysts

Vegetation Module Reference Table (continued)

Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
V6: What are important functions of riparian vegetation relative to watershed processes?	• Riparian/wetland vegetation map prepared for V2 and V3 • Anecdotal information • Recent riparian assessments	• Develop preliminary list of riparian vegetation functions	• Multi-function Proper Functioning Condition assessment • Wood recruitment potential ratings approaches • Wood recruitment modeling • Shade assessment
V7: What are important functions of wetland vegetation relative to watershed processes?	• Riparian/wetland vegetation map prepared for V2 and V3 • Anecdotal information • NWI maps • Soil surveys and hydric soils lists • Recent wetland delineations or assessments • Local sensitive or critical areas inventories	• Develop preliminary list of wetland vegetation functions	• Wetland Evaluation Technique • Hydrogeomorphic Classification System
V8: What land use practices have influenced or could influence vegetation conditions and functions?	• Anecdotal information • Aerial photos • Maps/GIS data	• Document location and approximate extent of changes identified from remote or historical sources (reconnaissance level)	• Detailed analysis of individual land use types • Quantitative assessment of vegetation modification (change in vegetation area or functions provided)

Level 1 Assessment

Step Chart



Data Requirements

- Map of watershed with stream network shown. The map should preferably indicate either stream order or any regulatory categorization used locally (e.g., "Water Types" or "Stream Classes"). If GIS maps cannot be generated, USGS topographic maps (1:24,000 scale) will be sufficient.
- Any existing vegetation reports and maps that differentiate basic land covers or define ecological zones.
- Floodplain surveys and maps (FEMA or other source).
- Any wetland maps or recent wetland delineations (e.g., NWI).
- Recent aerial photos or satellite images of sufficient resolution for identifying vegetation types.
- Historical aerial photos or other data describing historical vegetation conditions (e.g., historical land survey notes, fish habitat surveys, or USFS forest distribution maps).
- A list or inventory of threatened, endangered, or sensitive plant species found in the region (federal or state natural resource agencies).
- Soil surveys and hydric soils lists.

Products

- Form V1. Vegetation category summary
- Map V1. Upland vegetation
- Map V2. Riparian/wetland vegetation
- Map V3. Land use practices that affect vegetation
- Vegetation report

Procedure

The primary objectives of the Vegetation assessment are as follows:

- To characterize vegetation types that exist in upland areas of the watershed.
- To characterize vegetation types that exist in riparian and wetland areas of the watershed.
- To identify land uses or land use practices that have caused or contributed to changes in vegetation.
- To identify watershed-related functions provided by vegetation in uplands, riparian areas, and wetlands.

Step 1. Collect background vegetation information

Although the "Data Requirements" section lists items that may be useful, the critical elements are as follows:

- A watershed map that shows the stream network to serve as a base map.
- Existing vegetation information describing current or past vegetation in the watershed (Box 2). This information could consist of maps, photos, site surveys, plant studies, monitoring data, etc. (Box 3).
- Remote data resources, such as aerial photos or satellite images.
- A list of rare or culturally significant plant species present in the watershed (Box 4).

Community Resources

Box 2. A practical note

Although the analyst may be able to locate data resources in libraries or on the internet, a good short-cut may be to contact an individual who has a thorough knowledge of the available documentation on resources in the assessment area. Knowledgeable persons often include local land managers or agency employees with long-term involvement in resource issues. They may be willing to loan information the analyst can review or reproduce.

Box 3. Places to look for vegetation maps

- Tribal resource agencies
- BIA
- BLM
- USFS
- NRCS
- State or local agencies (particularly forestry, wildlife, fisheries, or water quality oriented)
- University or community libraries

Box 4. Examples of culturally significant riparian and wetland species

Brown ash (Penobscot River basin, Penobscot Indian Nation, Maine): Riparian tree species valued for traditional basket making.

Common reed (Cibecue Creek basin, White Mountain Apache, Arizona): A plant used to make arrow shafts and ceremonial objects. Interviews with cultural advisors consistently revealed that common reed used to be more abundant. Field trips with students led to the identification of places where this plant grew. These areas became source areas for transplants used in restoration projects.

Camas (Quinault River watershed, Quinault Nation, Washington): Wet-meadow plant whose tuberous roots were a preferred native food source. Quinaults traditionally introduced fire to maintain forest openings (camas prairies) in order to maintain preferred growing conditions.

Step 2. Select vegetation classification systems

Separate classification systems will be needed for upland, riparian, and wetland areas, although some consistency in approach among the three is desirable. Because there is no single system that will be appropriate for all possible locations, the analyst must ultimately choose or develop a useful system. Consider the following when choosing a vegetation classification system:

- Start by reviewing any classification systems already in use. Use of an existing system will facilitate input from individuals who may use these systems. It may be necessary to either lump or sub-divide existing categories to provide an array of categories that provides a balance between simplicity and detail.
- If no classification systems have been used within the watershed, it may be possible to import a system being used for similar neighboring areas. Classification systems should be based on the species composition where possible rather than on vegetation age or size, which change over time.
- A good system will distinguish vegetation differences that correspond to important functional differences. For instance, distinguishing riparian conifer forest from willow vegetation is important because conifers can provide wood debris to the channel, while shrubs cannot (Box 5).

Box 5. Notes on vegetation classification systems

Countless systems have been developed to characterize vegetation communities, some based on gross differences (forest vs. desert), some distinguishing subtle differences in prevalence among the same handful of species (see example below). The best classification system for use in the Vegetation module is the simplest system that captures important functional differences among vegetation categories. The chosen system should also be mapable at the scale being used for other products. Depending on the size and complexity of the watershed, a manageable system would result in approximately 5-20 distinct vegetation categories.

The example below shows how vegetation can be classified at finer levels of resolution. Using a finer scale system, such as the Plant Associations system on the right, will involve considerably more complication and difficulty in delineating vegetation types accurately without extensive field checking. The hypothetical watershed used to produce this table contains three Major Groups: Alpine, Forest and Range vegetation. If each of these Major Groups can be broken into three subcategories (i.e., Dominant Vegetation Types), and each of these can be broken further into three Plant Associations, that will result in nine Types and 27 Plant Associations. Thus, delineating at the intermediate level is most practical for watershed scale assessments. It is also likely that functional differences between the Plant Association categories are fairly minor.

Example of vegetation classification system

	Overall level of detail		
	General *Major Groups*	**Intermediate** *Dominant Vegetation Types*	**Specific** *Plant Associations*
	1 *Alpine*	**2a** *Spruce/fir*	**2bi** *Lodgepole/huckleberry*
	2 *Forest*	**2b** *Lodgepole pine*	**2bii** *Lodgepole/pine grass*
	3 *Range*	**2c** *Juniper*	**2biii** *Lodgepole/rabbit brush*
Applicability for Vegetation module:	Probably too broad	May be OK	Probably too detailed

- Ideally, each of the categories should be identifiable from remote data, such as aerial photos. If category distinctions are too subtle, they may not be easily distinguishable and could become cumbersome to map and use (Box 6).

Step 3. Collect information on existing vegetation

This step, which consists of collecting and compiling vegetation information, comprises the bulk of new information generated within the Vegetation module.

Box 6. A methodology note: characterization of upland vs. wetland and riparian vegetation

Although the steps for characterizing and mapping vegetation are essentially the same for upland, riparian, and wetland vegetation, it may or may not be best to gather and process data simultaneously. The best approach depends on the information sources available.

If the analyst will be using the same information source(s) to characterize upland, riparian, and wetland vegetation (e.g., aerial photos for all), it may be most efficient to do all concurrently. On the other hand, if the analyst will be using separate sources (e.g., existing vegatation maps for uplands vs. aerial photos for riparian), it may be best to do the steps separately for each vegetation type. There might be intermediate options as well, such as doing some of the steps together. For instance, field verification of upland and riparian vegetation could probably be conducted during the same field visit.

Upland vegetation

a. Make or acquire a base map that will serve as a draft upland vegetation map upon which to collect notes and do preliminary mapping. USGS topographic maps are a good option; most already distinguish forested areas from non-forested and agricultural areas.

b. Consult any existing information on vegetation. Record information on the draft upland vegetation map.

c. Inspect vegetation on aerial photos or other remote data sources. If little existing vegetation information is available, aerial photos may be the primary source. Alternatively, even if vegetation types have been previously mapped, photos may be useful to verify accuracy (especially if existing maps are out of date) or fill in blank areas. In addition, the analyst may decide to sub-divide or lump some vegetation categories that were used.

d. Record observations of land use impacts (Box 7).

e. Visit a sample of sites to validate or refine boundaries. Depending on access and terrain, it might be possible to review sizable areas from a vehicle. Field inspection might reveal vegetation differences that correspond with elevation, aspect,

Box 7. Recognition of vegetation alteration on aerial photos

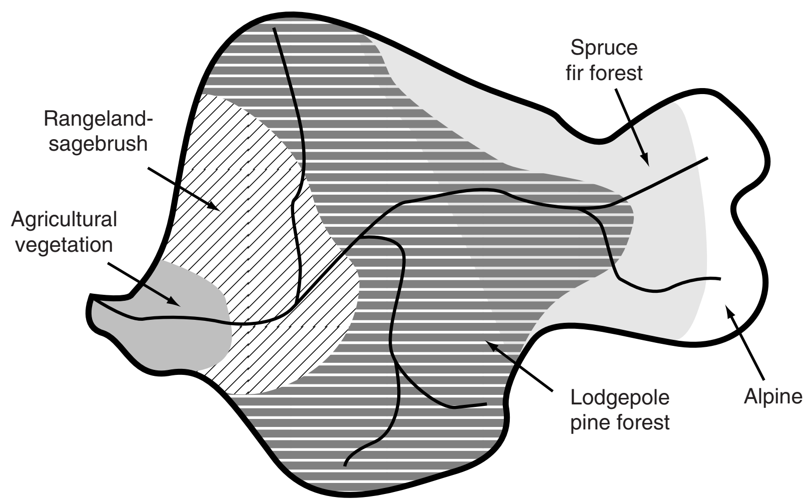
Clearing for agriculture - tilled soil or smooth-appearing crop cover will be evident.
Logging - distinct patches without trees likely indicate clearcut harvest; selective logging will be less obvious, but areas of sparse forest or yarding roads may be apparent.
Grazing - will be hard to see from photos if dispersed; there may be visible trails along fence-lines or bare spots where animals congregate.
Fire - darkened ground inside burned areas; edge of burn will be distinct, but irregularly-shaped; may be able to see plant remnants, such as burned trees.
Mining or quarries - pits will show up as light-colored areas where rock is exposed; hole may be visible when viewed in stereo; underground mines may be identified by piles of tailings, mine buildings, etc.

When confronted with photo interpretation difficulties, it may be possible to find someone with local knowledge or excellent photo skills to consult.

or landform type, and that information could be extrapolated to inaccessible areas using topographic maps or aerial photos.

f. Fill in Form V1 for each vegetation category and create the final upland vegetation map (Map V1; Figure 1).

Figure 1. Sample Map V1. Upland vegetation



Riparian and wetland vegetation

a. Make or acquire a base map that will serve as the draft riparian/wetland vegetation map. This map should show channels and wetlands, as well as roads and section lines if possible, to make it easier to transfer information from maps or aerial photos. The analyst may need to do some additional research to locate wetlands (Boxes 8 and 9).

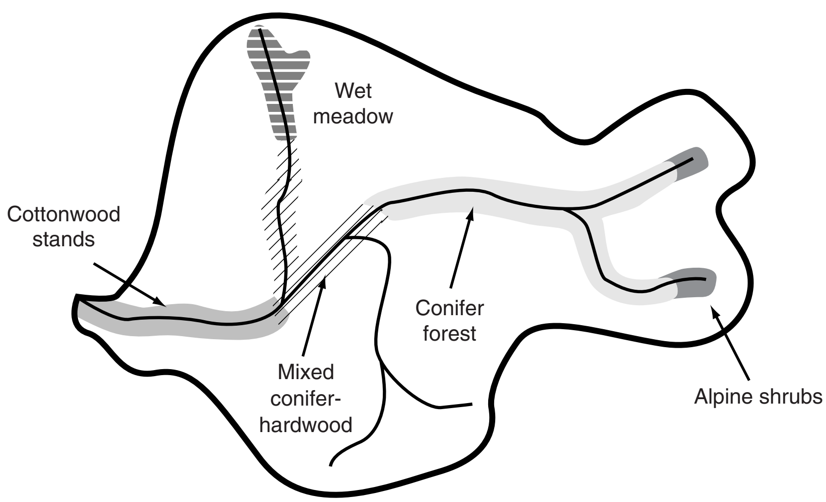
b. The remaining procedure is the same as for upland areas (i.e., sub-steps b. - f., above), with a few exceptions. For aerial photo evaluation (sub-step c.), the analyst will first need to determine an evaluation width (Box 1). For field verification (sub-step e.),

Box 8. Locations of channels and wetlands

USGS topographic maps generally provide good representation of the channel system, although they may not show all of the smaller channels and wetlands, especially in forested areas. Probably the best widely-available source to provide a more complete inventory of wetland locations is the National Wetlands Inventory (NWI). The NWI covers most of the United States and uses the USFWS classification system (Cowardin et al. 1979), described in Box 9. Likely places to find local NWI maps are county planning agencies or the NRCS. There may also be independent wetland studies, such as site-specific reports prepared for individual projects. In some cases, aerial photos (especially large-scale or color) can be used to help map small streams or wetlands.

the analyst will probably find that inspection of riparian and wetland areas will require more on-foot visits, rather than vehicle inspection. Riparian and wetland vegetation information can be combined on one map (Map V2; Figure 2).

Figure 2. Sample Map V2. Riparian/wetland vegetation



Box 9. Wetland definition and classification

Because wetlands are regulated under federal laws, a system was needed to determine exactly which criteria would distinguish wetlands from uplands. The widely used definition of wetlands is based upon the presence of three indicators: wetland plants, hydric soils, and surface water or soil saturation at some time within the growing season (USACE 1987).

The analyst will not need to make wetland determinations for the Vegetation module but will likely use a system for wetland classification. The most common system for wetland classification is one used by the NWI: the USFWS or Cowardin system (Cowardin et al. 1979). This system indicates the water feature (marine, riverine, etc.) and vegetation type (forest, shrub, etc.) of each wetland. This system is well suited for use with the Vegetation module, especially if NWI inventory data are already available. The second commonly used system is the Hydrogeomorphic Classification System (Smith et al. 1995), which classifies wetlands on the basis of hydrologic and landform setting. The Hydrogeomorphic Classification System is well suited for determining the role of wetlands in watershed processes, but it has the disadvantage of not including any characterization of vegetation.

Step 4. Identify and summarize changes from historical conditions and other land use impacts

Changes in vegetation conditions can be determined from aerial photos or other documentation. Historical changes can be easily determined if they are obvious and long-term, such as conversion to agriculture or urban use (Box 10). It may be harder to identify gradual changes in vegetation (e.g., from long-term grazing or fire suppression) unless they have already been documented.

Community Resources Historical Conditions

Ongoing land use is easier to identify because it can be verified at any time. For instance, rather than plotting individual clearcuts from logging in the past decade, delineate the entire area managed for logging over a longer period. These changes can be identified from aerial photos, field visits, and local knowledge.

Box 10. Documenting historical vegetation modification

An example from the Cibecue Creek Watershed, White Mountain Apache Reservation, Arizona

In the 1950s and 1960s, the Cibecue Creek watershed was the subject of an extensive program to convert areas of native pinyon-juniper woodlands, riparian cottonwoods, and other vegetation types to grass cover. The stated goals of the project were to expand grazing resources, provide work for local Apache residents, and "possibly increase water yield from the watershed." Thirty years later, accelerated erosion was more evident than were water yield increases (which did not result), and the net benefits from this program were debatable. Despite the apparent failure of this project to meet its stated goals, it did produce some information resources that may be valuable for watershed assessment, such as pre-treatment vegetation and soils data. Also, the location and extent of areas subjected to treatment were fairly well documented.

This vegetation conversion project differs from most other instances of large-scale vegetation conversion in that it occurred relatively recently and was well documented. Such documentation is extremely valuable for assessing the nature of impacts that have resulted from historical vegetation changes.

Box 11. Common ecosystem functions attributed to vegetation

Upland vegetation

- Effects on erosion (soil cover, root strength, organic matter production)
- Effects on hydrologic processes (evapo-transpiration, snow accumulation and melt)
- Habitat and cover for biota

Riparian vegetation

- Influence on bank stability and channel morphology
- Source of in-channel wood debris (mainly important to physical channel processes)
- Source of litter and fine organic input (food source for biota)
- Habitat for biota
- Moderation of water temperatures from shade (Box 12; also covered in Water Quality module)

Wetland vegetation

- Sediment trapping
- Source of wood debris for habitat
- Nutrient uptake
- Habitat and cover for biota

Assessment of land uses and practices is necessary to determine causes for alteration of riparian areas, removal of vegetation, and consequent effects on streams and community resources. The assessment procedure requires aerial photo interpretation and limited field checking.

a. **Identify the land use practices.** Most activities should have been identified in the Scoping process, while observations from the aerial photo analysis should provide supporting information on the location and extent of land use practices.

b. **Identify resulting impacts.** This should include a description of the changes to vegetation species and communities. In many cases, specific practices have changed over time, sometimes for the better (e.g., restrictions on grazing or logging along streams may have been implemented). As possible, such changes should be noted and considered in sub-step d.

c. **Make a list of possible impacts to vegetation functions**. For Level 1 assessments, functions will be inferred for each general vegetation type (Box 11). Reductions in function will be

Box 12. Assessment of riparian shade effects on water temperature

In some watersheds, shade from riparian vegetation plays a major role in maintaining cool stream temperatures required by cold water species, such as trout and certain amphibians. In other streams (large rivers for example), the influence of riparian shade is minimal and upstream dams or water withdrawals are dominant influences. Because of the variable importance of shade effects upon water temperatures, water temperature issues are assessed in the Water Quality rather than Vegetation module. In watersheds where riparian vegetation has an important influence, it may make sense for the Vegetation analyst to undertake a widespread evaluation of riparian shade. Discussion between the Vegetation and Water Quality analysts will be helpful to determine an effective approach for the two modules.

assumed to correspond to the extent that the original vegetation has been altered; however, this assumption is not always accurate. Therefore, the preliminary identification of impacts to functions can provide hypotheses for further Level 2 assessment.

d. Evaluate trends in recovery or restoration (Box 13). Evaluate the long-term outlook for recovery of impacted areas if the practices continue or are discontinued.

e. Present results of the land use assessment. Land use practices that affect vegetation should be identified on Map V3 (Figure 3). More than one map may be necessary if there are many land use impacts that overlap for a given location.

f. Summarize results. Create a table or a narrative to present at Synthesis that describes land use practices, impacts on functions, and trends in recovery or restoration.

Box 13. Recovery potential from land use impacts

Natural recovery likely

- Logging
- Grazing
- Flood damage
- Fire

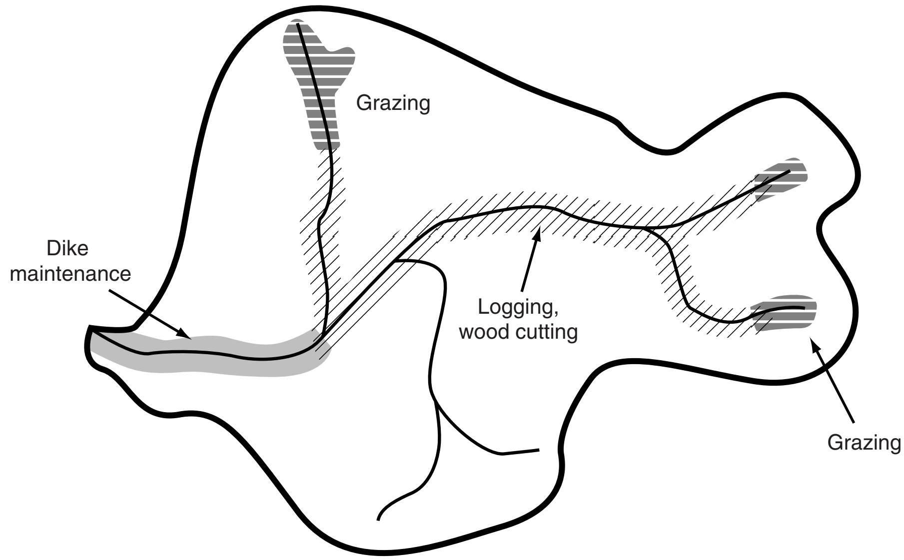
Restoration possible

- Conversion to agriculture
- Vegetation conversion

Restoration difficult

- Conversion to urban
- Floodplain or wetland modification (e.g., diking, filling, etc.)

Figure 3. Sample Map V3. Land use practices that affect vegetation



<u>Step 5. Produce Vegetation report</u>

In addition to the three maps and the vegetation summary forms, the Vegetation report is an important end-product of this assessment. The report need not be elaborate or lengthy but should document the following components:

- **Assessment methodology:**
  - Vegetation classification systems chosen and why.
  - Riparian assessment width used and justification.
  - Primary information sources: vegetation studies, maps, aerial photos, field investigation, etc.

- **Results of the assessment:**
  - Distribution of upland, wetland, and riparian vegetation categories.
  - The extent and severity of historical vegetation modification and ongoing land use practices.
  - Watershed functions provided by each vegetation category.

- **Topics for Level 2 assessment; examples include the following:**
  - Trends in vegetation that result in changes in vegetation functions..
  - Functions requiring further assessment (e.g., nutrient cycling, wildlife habitat).
  - Issues involving rare or culturally significant plant species.

Level 2 Assessment

The information generated from a Level 1 assessment, such as the key vegetation types in uplands, wetlands, and riparian areas across the watershed, can be useful for guiding a Level 2 assessment (Table 1). A Level 1 assessment may not address certain priority watershed issues or processes related to vegetation except in a broad or hypothetical way. Synthesis brings the Vegetation assessment into a broader context of watershed issues and provides an excellent forum to identify priority issues relating vegetation functions to aquatic resources and watershed processes (Box 14).

Box 14. Examples of vegetation-related priority issues and hypotheses suitable for Level 2 assessment

Although many potential priority issues are likely to arise during Synthesis, the analyst will need to select a manageable number for assessment. Once priority issues have been chosen, it will be valuable to develop hypotheses (i.e., testable statements that are narrower and specifically focused on the role of vegetation). Hypotheses that involve issues covered by other modules will require collaboration with other analysts.

Issue: Streambank erosion has increased.
Hypothesis: Grazing has reduced the abundance and vigor of bank-reinforcing vegetation.
Assessment Method: Land use or riparian functions.
Collaboration: Assessing bank erosion should involve the Channel analyst.

Issue: Waterfowl habitat has been reduced.
Hypotheses: Wetland filling for agricultural use in the last 100 years has resulted in reduced waterfowl habitat.
Assessment Method: Historical change or wetland functions.
Collaboration: Community Resources analyst.

Issue: Grass species have been gradually replaced by juniper and sagebrush.
Hypothesis: Vegetation composition has changed substantially as a result of fire suppression.
Assessment Method: Historical change.
Collaboration: Community Resources analyst may be able to help assess the importance of reduced forage.

Issue: Input of wood debris that creates trout habitat in streams has been reduced.
Hypothesis: In riparian areas that have been logged, there is less wood debris entering the stream or available for recruitment.
Assessment Method: Evaluation of specific land use practices or riparian functions.
Collaboration: Aquatic Life analyst should be consulted to guide assessment of fish habitat.

The Level 2 assessment employs more focused assessment techniques to address more specific issues (Table 1). Because the major task of the Level 1 assessment is vegetation characterization, the first three critical questions will have been largely covered. It is more likely that priority issues for Level 2 will fall within the topics covered by Critical Questions 4-8: changes from historical conditions, vegetation functions, and effects of individual land uses.

Table 1. Summary of Level 1 products and possible avenues for Level 2 assessment

Topic	Products from Level 1 assessment	Considerations for Level 2 assessment
Types and locations of primary vegetation categories	Maps of vegetation categories	More effort may be required to improve the resolution of vegetation category locations using additional field effort or photo interpretation.
Vegetation changes from historical conditions	Major changes noted on vegetation maps	Detailed analysis of historical changes may be useful, especially if an understanding of target conditions is necessary and undisturbed reference sites are not available.
Functions of upland, riparian, and wetland vegetation	Preliminary lists of functions for each vegetation type	Analysis of individual functions and their importance to ecological processes can be valuable.
Effects of land use practices on vegetation	Information on land use practices and changes in vegetation	Further analysis could be valuable to evaluate land use effects and to identify changes in practices necessary to improve vegetation conditions or functions.

Because this module is designed for use across a very broad array of natural landscapes and vegetation types, there is no single method that will be suitable for all Level 2 issues and settings. Rather, this discussion provides an outline of the general steps and several broad approaches to vegetation assessment. Many methods have been developed for use in various parts of the United States. The analyst will need to choose from existing methods or develop a method suitable for the vegetation issues at hand. For this reason, the Level 2 assessment relies heavily on the skills and judgement of the analyst to identify methods suitable for the local environment and adapt one of these for the local landscape and issues identified.

There are several general approaches that may be useful in evaluating the priority issues of a Level 2 Vegetation assessment. The following section is designed to introduce these approaches, to help the analyst determine which are best suited to the identified issues, and to provide limited guidance on how to pursue them most effectively. The organization of the general approaches follows the issues listed in Table 2.

Table 2. Methods available for Level 2 assessment

Issues	Critical questions	Information requirements	Level 2 methods/tools
Types and locations of primary vegetation categories	V1-V3	Various remote and direct sources: aerial photos, maps, GIS, field surveys, etc.	• Further investigation with aerial photos or field visits • Detailed assessment of special habitat types
Vegetation changes from historical conditions	V4	Any documentation of historical vegetation conditions.	• Analysis of historical documentation (see Sedell and Luchessa 1982, Platts et al. 1987)
Functions provided by upland, riparian, or wetland vegetation	V5-V7	Information on upland, riparian, and wetland functions. Information requirements differ among methods.	**Upland functions:** • Various methods depending on upland function; coordinate with other analysts **Riparian functions:** • Wood recruitment potential ratings (e.g., WFPB 1997, Watershed Professionals Network 1999) and recruitment modeling (e.g., Van Sickle and Gregory 1990) • Multi-function Proper Functioning Condition assessment (Prichard et al. 1998) • Shade assessment; collaborate with Water Quality analyst **Wetland functions:** • Wetland Evaluation Technique (Adamus 1991) Hydrogeomorphic Approach (Smith et al. 1995)
Effects of individual land use practices on vegetation	V8	Information on specific land use practices: information from field investigation, aerial photos, GIS, agencies, etc.	• Various regionally-applicable methods

Evaluation of Historical Vegetation Changes

Method summary

Identify long-term changes in upland, riparian, or wetland vegetation using documentation of historical conditions, such as old aerial photos, land survey notes, or narratives.

Primary benefits

A characterization of historical conditions can be extremely helpful in understanding long-term trends in resource conditions (e.g., "Is vegetation removal responsible for the widening of streams observed over the last 50 years?"), as well as providing a detailed target for restoration. The historical picture is particularly useful for environments that have been substantially modified and thus lack relatively non-degraded locations to serve as reference sites. Historical vegetation conditions can also be used to create targets for the desired levels of functions or to evaluate the degree of change in present vegetation. In addition, this approach is the only one likely to provide insight (though indirect) into the vegetation-influencing role of natural disturbance agents (e.g., wildfire, beaver activity) that have been diminished or are no longer active.

Limitations

The extent and reliability of documentation available to support such an assessment is highly variable from place to place. Documentation of conditions prior to 1900 is likely to be quite limited, which reduces the applicability of this approach in areas with a long history of land modification. Another challenge is extrapolating information from photos or descriptions, which are typically site-specific, to the landscape scale. One final caution is that because historical descriptions are largely qualitative, their use is subject to considerable interpretation. Levels of resolution and confidence may be inadequate to satisfy all community members in contentious situations.

Resources needed

- Old aerial photos with coverage that may go back to the 1930s or 1940s.
- Old landscape photos.
- Old maps or land survey notes (land survey notes often include descriptions of vegetation).

- Written or oral narratives of tribal elders or long-time residents.
- Field surveys (especially useful in areas where remnants of past vegetation, such as tree stumps, persist).
- Any other historical documentation.

Other considerations

Practically speaking, a historical vegetation study should be undertaken only if 1) the types of information generated will be valuable, and 2) a preliminary inventory indicates that sufficient documentation is available to produce a satisfactory portrayal.

Although historical investigations are increasingly common, there is little documented guidance available (see Table 2 for two references). To a large extent, the quality of the product depends on the diligence of the analyst.

Evaluation of Upland, Riparian, or Wetland Vegetation Functions

Method summary

Evaluate the effectiveness of present vegetation at providing one or more key ecosystem functions, such as streambank reinforcement or wildlife habitat. Ideally this can be done using an existing methodology; however, in some situations, the analyst may choose to modify an existing method to fit local conditions.

Primary benefits

Functions assessment has numerous advantages, particularly when an existing evaluation tool is available. Application of a widely accepted method takes advantage of the familiarity and confidence associated with the method. Methods that focus on one or two key functions are likely to be more objective than are holistic methods (Box 15). A function-based approach is best suited to an area in which a relatively unaltered vegetation community exists to serve as a standard for comparison.

Limitations

The utility of an assessment that focuses on one or two individual functions depends on choosing appropriate functions, such that other key functions are not overlooked. If

Box 15. Two general approaches to functions assessment: individual function and holistic, multi-function

Individual function assessments assess one or more functions directly by evaluating components of the vegetation community that correspond with the levels of function provided. Ideally, such methods are supported by a strong scientific understanding based upon studies that have defined quantitative linkages between vegetation conditions and levels of function. The assessment of one or several well-understood functions at the exclusion of others is often justified by the presumption that vegetation conditions that provide assessed functions will also provide acceptable levels of other functions not considered. Examples of this approach include watershed analysis methods used in both Oregon (Watershed Professionals Network 1999) and Washington (WFPB 1997), both of which evaluate only shade and wood debris input for riparian vegetation.

Holistic, multi-function assessments assess function levels on the basis of the similarity of existing vegetation to a pre-determined "reference condition" assumed to provide acceptable levels of all desired functions. Some methods of this type simply assume that if the vegetation contains all the right components, the functions will follow, while others include a qualitative evaluation of various individual functions, as in the Functional Checklist used to evaluate Proper Functioning Condition (Prichard et al. 1998).

an existing assessment method is available, the relevance of the results depend on 1) the effectiveness of the method, and 2) the suitability of the method to the site where it will be used. Functions assessment may be poorly suited to the evaluation of lingering impacts from conditions or practices that have been discontinued.

Resources needed

- Documentation of any existing assessment methods available.
- Consultation with individuals experienced in use of these methods.
- Maps, aerial photos, or other resources required by the method.

Other considerations

Identification of key functions is an important step. Box 11 in the “Level 1” section lists several vegetation functions to consider, although there may be others important locally that are not included.

Finding and choosing a suitable method is also critical, and it is worthwhile to check with local experts first. If a suitable method cannot be found for a priority issue, check the library or internet to find methods used in other locations that could be modified. Another option is to use a general, multi-function method, such as the Proper Functioning Condition approach (Prichard et al. 1998).

Evaluation of Specific Land Use Practices

Method summary

In watersheds where several land use types are dominant, it may be useful to assess the impacts of specific land uses individually. The assessment will rely on the same techniques used for the historical change and function assessment approaches discussed previously. The unique aspect of the land use specific approach is that it includes an in-depth assessment of the specific land use practices involved to support detailed recommendations.

Primary benefits

This approach will be highly effective in watersheds or sub-basins where there is a single, obvious, dominant land use practice occurring. This approach should be considered for watersheds where information to support revising particular land use practices is desired.

Limitations

The focus on a single land use may increase the potential to miss important impacts of secondary land uses or processes. Also, it may be hard to evaluate recent changes in practices unless some time has passed.

Resources needed

- Aerial photos.
- Maps and GIS data of logged areas, grazing allotments, etc.
- Land use maps.
- Consultation with and information from land managers or agencies involved in the particular land use of interest:
  - All land use types - tribal or county planning/zoning agencies.
  - Forestry - forestry agencies or companies.
  - Agriculture/grazing - NRCS.

Community Resources ▶

Other considerations

It is important to assess not just the location of practices but the extent of physical effects, such as soil disturbance, vegetation damage, and changes in the prevalence of plant species. It is also important to evaluate time trends, such as changes in practices over time or recovery trends.

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Form V1. Vegetation category summary

Vegetation category:	**Location:** ☐ Upland ☐ Riparian ☐ Wetland
Primary species:	
Unique or culturally valuable plant species present:	
Land use impacts:	
Functions:	
Field sites visited:	

Glossary

303(d) List:
A list of streams, lakes, and estuaries where state water-quality standards are not met or where technology-based controls are not sufficient to achieve standards.

Adsorption:
The retention of atoms, ions, or molecules on the surface of another substance.

Aggradation:
The accumulation of sediment, usually implying an increase in deposit thickness.

Aeration:
The act of mixing a liquid with air (oxygen).

Aerobic:
Able to live, grow, or take place only when free oxygen is present.

Alluvium:
Unconsolidated material (sediment) deposited by flowing water.

Alluvial fan:
A landscape feature whose surface is shaped like an open fan or a segment of a cone and is formed by the accumulation of sediment and organic material deposited by flowing water.

Ammonification:
The production of ammonia from the decomposition of organic matter.

Anaerobic:
Able to live, grow, or take place where free oxygen is not present.

Anecdotal information:
Information based on descriptions of individual cases rather than on controlled studies.

Anoxic:
The total deprivation of oxygen.

Aquifer:
A natural underground layer of porous, water-bearing materials (sand, gravel) usually capable of yielding a large amount or supply of water.

Basin:
(see Watershed)

Baseflow:
Groundwater discharge to the stream; the flow not accounted for by storm runoff.

Bedload:
Sediment carried along a channel bed by sliding, rolling, or bouncing.

Bedrock:
Solid rock that underlies the earth's surface.

Beneficial use:
Taken from Section 303(c)(2)(A) of the Clean Water Act and state statutes, these include municipal, industrial, and domestic water supply; contact recreation; non-contact recreation; fish and wildlife; and agriculture use (irrigation).

Benthic:
Of or pertaining to the bottom of a body of water.

Best management practice (BMP):
A method that has been determined to be an effective, practical means of preventing or reducing pollution or protecting resources; generally applies to non-point sources of pollution.

Bioaccumulation:
The process by which a contaminant accumulates in the tissues of an organism.

Biochemical oxygen demand (BOD):
The amount of oxygen consumed by microorganisms (mainly bacteria) and by chemical reactions in the process of degrading organic matter in water.

Biota:
The animal and plant life of a given region.

Braided stream:
A channel pattern with multiple threads of streamflow.

Bulk density:
Mass per unit of volume.

Calcareous:
Of or containing calcium carbonate, calcium, or limestone.

Carbonaceous:
Of or containing carbon.

Cartographic:
Of or pertaining to maps.

Channel:
A stream or river bed; generally refers to the physical form where water commonly flows.

Channel morphology:
(see Morphology)

Channel response:
Changes in the shape or structure of a channel.

Channelization:
The act of straightening a stream; typically widens and deepens the stream as well to improve the flow of water.

Chelation:
The joining together of metals (such as copper) with certain organic compounds.

Coarse sediment:
Particles that are typically considered gravel-sized and larger; generally transported as bedload.

Chemical oxygen demand (COD):
A measure of the oxygen-consuming capacity of inorganic and organic matter present in water; the amount of oxygen consumed from a chemical oxidant in a specific test.

Coliform:
A group of bacteria found in the intestines of warm-blooded animals (including humans), also in plants, soil, air, and water. Fecal coliforms are a specific class of bacteria that only inhabit the intestines of warm-blooded animals. The presence of coliforms is an indication that the water is polluted and may contain pathogenic organisms.

Colloidal:
Of or pertaining to very small, finely divided solids that do not dissolve and remain dispersed in a liquid due to their small size and electrical charge.

Colluvium:
The soil and rock debris on a hillslope that has been transported from its original location.

Community resource:
An environmental asset that has important cultural, economic, or spiritual value for the people of the region (e.g., medicinal herbs, drinking water, agricultural land, fish and wildlife).

Critical questions:
A tool used in the technical modules to help identify the watershed assessment methods that will address the issues of concern.

Cumulative effects:
The combined environmental effects over time of multiple land use activities, typically in a watershed area.

Degree day:
A rough measure estimating the amount of heat in a given area; it is defined as the difference between the mean daily temperature and 65 degrees Fahrenheit.

Delivery potential:
The likelihood that a hazardous input will be transported to a community resource.

Denitrification:
The anaerobic biological reduction of nitrate to nitrogen gas.

Dichotomous key:
A system that classifies materials by separating choices into two categories.

Dissection frequency:
The density of channels in a specified area.

Dissection pattern:
The distribution of channels in a specified area.

Disturbance event:
An uncommon occurrence from a natural agent, such as floods, fires, or hurricanes, that has a significant influence on ecosystems

Diurnal:
Daily

Dry ravel:
(see Ravel)

Ecoregion:
An area with a relatively uniform pattern of terrestrial and aquatic ecological systems.

Effluent:
Wastewater, treated or untreated, that flows out of a treatment plant, sewer, or industrial point source, such as a pipe. Generally refers to wastes discharged into surface waters.

Eh:
The electrical potential required to transfer electrons from one compound or element (the oxidant) to another compound or element (the reductant); the reduction-oxidation potential. Typically used as a qualitative measure of the state of oxidation in water treatment systems.

Empirical:
Relying upon or gained from experiment or observation.

Entrenchment:
(see Incision)

Erosion:
The removal of sediment or rock from a point in the landscape.

Eutrophication:
The increase in the nutrient levels of a lake or other body of water; this usually causes an increase in the growth of aquatic animal and plant life.

Evapotranspiration:
The release of water vapor into the atmosphere by the combination of direct evaporation and transpiration by plants.

Fan:
(see Alluvial fan)

Fecal coliform:
(see Coliform)

Fine sediment:
Particles that are typically sand-sized and smaller; generally transported as washload.

Fixation:
(see Nitrogen fixation)

Floodplain:
A nearly level alluvial plain that borders a channel and is occasionally inundated by floods (unless artificially protected). The landform is formed by sediment transport and deposition from flows over the streambank and lateral movement of the stream.

Fluvial:
Of or pertaining to streams; produced by stream action.

Functions:
The contribution of an ecosystem element, such as vegetation, to the natural working of the ecosystem.

Geomorphic channel type:
A stream reach or group of reaches that respond similarly to changes in landscape forming processes, such as water runoff, erosion, and vegetation growth.

Geomorphic process:
A landscape altering system, such as water runoff or erosion, that influences the movement and shape of the physical landscape.

Geomorphic responsiveness:
The degree to which a stream channel changes its morphology or behavior due to alterations in landscape forming processes, such as water runoff, erosion, and vegetation growth.

Geomorphology:
The study of physical landscapes (landforms) and the processes that create and mold them.

Geographic information system (GIS):
A computer system designed for storing, manipulating, analyzing, and displaying data in a geographic context, usually as maps.

Glacial:
Of or pertaining to distinctive processes and features produced by or derived from glaciers and ice sheets.

Gradient:
The slope or incline measured by the change in elevation over a specified length. Measurement units may consist of either a dimensionless proportion (percentage) or an angle based on the 360-degree circumference of a circle.

Groundwater:
The water found below the surface of the land and contained in the pore spaces of saturated geologic media (sand, gravel). Groundwater is the source of water found in wells and springs.

Hazardous input:
Any element of the ecosystem that can affect a community resource (e.g., sediment, nutrients, heat)

Headwaters:
The upper watershed area where streams generally begin; typically consists of 1st- and 2nd-order streams

Hillslope process:
(see Geomorphic process)

Hydrogeology:
The study of the interaction of groundwater and the surrounding soil and rock.

Hydrograph:
A graphical plot of streamflow data over time.

Hydrologic regime:
The system that describes the occurrence, distribution, and circulation of water on the earth and between the atmosphere.

Hyetograph:
A graphical plot of precipitation data over time.

Hypothesis:
An assumption that requires verification or proof.

Impervious surface:
A material that does not allow, or allows only with great difficulty, the infiltration of water.

Incision:
The downward cutting of a stream into the earth's surface.

Interception:
In hydrology, the accumulation of precipitation on vegetation and other above-ground surfaces and its evaporation during and after a storm event.

Interdisciplinary:
Interaction between different branches of knowledge.

Interstitial space:
The matrix of air or liquid between sediment particles; pore space.

Isohyet:
A line on a map along which all points receive the same amount of precipitation.

Karst:
A landscape influenced by the dissolving of limestone or gypsum; usually characterized by caves, sinkholes, and underground drainage.

Landform:
Any physical, recognizable form or feature of the earth's surface having a characteristic shape and produced by natural causes.

Landscape:
The traits, patterns, and structure of a specific geographic area, generally including its physical environment and biological composition.

Land type:
A feature on the landscape with a generally uniform shape and set of physical characteristics; often created by a single geomorphic process.

Leachate:
A liquid that results from water collecting contaminants as it trickles through waste material. Leaching may occur in farming areas, feedlots, and landfills and may result in hazardous substances entering surface water, groundwater, or soil.

Life history stage:
A portion of an organism's life with specific living requirements.

Loading:
(see Pollutant loading)

Loess:
Fine-grained material that has accumulated by wind deposition.

Low flow:
Minimum instantaneous streamflow during periods of low water runoff.

Macroinvertebrate:
A larger organism without a spinal column, such as an aquatic insect.

Mass wasting:
The dislodgment and downslope transport of earth material as a unit under direct gravitational stress. The process includes slow displacements such as soil creep and rapid movements such as landslides and avalanches.

Mainstem:
The primary, and generally largest, branch of a river.

Module:
(see Technical module)

Morphology:
The form and structure of an object.

National Pollutant Discharge Elimination System (NPDES):
A provision of the Clean Water Act that prohibits discharge of pollutants into waters of the United States unless a special permit is issued by the EPA, a state, or a tribal government on the reservation.

Natural disturbance:
(see Disturbance event)

Natural storage:
(see Watershed storage)

Nitrogen fixation:
The biological or chemical process by which elemental nitrogen from the air is converted to organic or available nitrogen.

Non-point source:
Pollution sources that are diffuse and do not have a single point of origin or specific outlet. The pollutants are generally carried off the land by water runoff during storms.

Organic litter:
Material derived from living plant organisms, such as leaves and branches.

Orthophoto:
A corrected and standardized aerial photo; generally at a scale of 1:24,000.

Oxidation:
Oxidation is the addition of oxygen, removal of hydrogen, or removal of electrons from an element or compound.

Parent material:
(see Bedrock)

Pathogens:
Microorganisms, such as bacteria, viruses, or parasites, that can cause disease in humans, animals, and plants.

Pathway analysis:
The exploration of the relationship between different forms or phases of a pollutant.

Peak flow:
Maximum instantaneous streamflow during periods of high water runoff.

Photosynthesis:
The manufacture by plants of carbohydrates and oxygen from carbon dioxide mediated by chlorophyll in the presence of sunlight.

Physiographic:
The natural, physical form of the landscape.

Planar:
On a level plane; flat.

Point source:
A stationary location or fixed facility from which pollutants are discharged or emitted. Also, any single identifiable source of pollution, such as a pipe, ditch, ship, ore pit, or factory smokestack.

Pollutant loading:
The quantity of a contaminant entering the environment (soil, water, or air); typically related to specific land use practices.

Protozoa:
One-celled animals that are larger and more complex than bacteria.

Rainsplash:
The displacement of sediment by bombardment of raindrops.

Ravel:
The rolling or sloughing of sediment due to loss of cohesion in surface materials.

Reach:
(see Stream reach)

Reaeration:
(see Aeration)

Recharge:
The process by which precipitation seeps into the groundwater system.

Reduction:
The addition of hydrogen, removal of oxygen, or addition of electrons to an element or compound.

Reference condition:
A state of being governed primarily by natural environmental processes and subject to minimal human impacts; a place that represents natural conditions for comparison purposes.

Refugia:

An isolated place of relative safety from danger and hardship; the only remaining high quality habitat within an area.

Resource sensitivity:

The responsiveness or susceptibility of an environmental asset to hazardous inputs.

Respiration:

The process in which an organism uses oxygen for its life processes and gives off carbon dioxide.

Rill erosion:

The movement of sediment through one of the first and smallest channels formed by water runoff. The size distinction is not formal but has generally been defined as narrower than 12 inches.

Riparian:

Areas adjacent to rivers and streams. These areas often have a high density, diversity, and productivity of plant and animal species relative to nearby uplands.

Roughness element:

Materials or forms that provide frictional resistance to the flow of water; examples include boulders, vegetation, and gravel bars.

Runoff:

That part of precipitation, snow melt, or irrigation water that runs off the land into streams or other surface water.

Sediment:

A solid particle, generally derived from rocks and minerals, that is being transported or has been moved from its place of origin.

Sediment budget:

An accounting of the sources, transport, and deposition of sediment in a watershed over time.

Sediment yield:

The amount of sediment passing a particular point in a watershed per unit of time.

Sheetwash erosion:

The movement of sediment by unchanneled, overland flow of water.

Sinuosity:

A measure of the number of turns or curves in a stream expressed as the stream length (wavelength) divided by the radius of curvature.

Snow-water equivalent:

The amount of water contained in a given volume of snow.

Soil creep:

The slow downhill movement of the soil mantle that results from disturbance of the soil by freeze/thaw processes, wetting or drying, or plastic deformation under the soil's own weight.

Spawning:

The process of bringing forth offspring for aquatic organisms, such as oysters, fish, or frogs.

Stakeholders:

Individuals or organizations with a direct personal, economic, legal, social, or cultural interest in the watershed.

Stream gage:

An instrument to measure the volume of streamflow over time, generally reported in cubic feet per second (cfs).

Stream order:

A stream classification system in which the headwater channel is of order 1, and when two channels of the same order join, they create a channel of one higher order (e.g., 1+1=2; 1+2=2; 2+2=3; etc.).

Stream reach:

A continuous portion of a stream between two designated points.

Sub-basin:

A watershed that is subset of a larger watershed.

Substrate:
The particles that constitute the bed of a channel.

Surface water:
All water naturally open to the atmosphere, such as rivers, lakes, reservoirs, ponds, streams, estuaries, and springs.

Suspended sediment:
Sediment carried within the water column of a stream.

Technical module:
A section of this document that provides guidance on conducting a science-based assessment on a set of community resources or watershed processes.

Terrace:
A low-gradient surface formed by fluvial aggradation or erosion when the stream flowed at a higher elevation in the landscape. The term usually implies that the surface is rarely, if ever, inundated by floods in the current climate.

Total Maximum Daily Load (TMDL):
Generally refers to plans under the Clean Water Act that limit the amount of pollutant discharge over time.

Topography:
The relative positions and elevations of the landscape that describe the configuration of its surface.

Transpiration:
The process by which water vapor is released to the atmosphere by living plants.

Tree throw:
The displacement of sediment held by the roots of a toppling tree; uprooting.

Trophic level:
A description of community structure based on the relationship between the production, consumption, and decomposition of energy (food) by organisms. Primary producers such as algae, herbivores such as deer, and carnivores such as wolves represent three different trophic levels.

Total suspended sediment (TSS):
(see Suspended sediment)

Turbidity:
The cloudy appearance of water caused by the presence of suspended and colloidal matter. Turbidity indicates the clarity of water and is an optical property of the water based on the amount of light reflected by suspended particles.

Unit pollutant loading rate:
(see Pollutant loading)

Upland:
An area of the terrestrial environment that does not have direct interaction with surface waters.

Volatilization:
The process of transferring a chemical from a liquid phase to a gas phase.

Washload:
Sediment carried in suspension by stream flow and that is of sizes not represented in the bed material.

Water budget:
A summation of inputs, outputs, and net changes to a water resource system over a period of time.

Waterbody:
Any type of surface water, such as a stream, lake, or wetland.

Water quality criteria:
Levels of water quality expected to render a body of water suitable for its designated use. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, industrial processes, or other designated use.

Water quality standards:
State-adopted and EPA-approved ambient standards for waterbodies. The standards prescribe the use of the waterbody and establish the water quality criteria that must be met to protect designated uses.

Watershed:
The land area that drains into a stream; an area of land that contributes water runoff to one specific delivery point (same as catchment, drainage, or basin).

Watershed approach:
A coordinated framework for environmental management that focuses public and private efforts on the highest priority problems within hydrologically defined geographic areas taking into consideration both ground and surface water flow.

Watershed process:
A natural system of interactions in the environment (e.g., water movement, erosion, nutrient cycling).

Watershed storage:
The capacity of an area to store precipitation in the snowpack, lakes, wetlands, and groundwater.

Wellhead protection area:
A protected surface and subsurface zone surrounding a well or well field that supplies a public water system and through which contaminants could likely reach well water.

Wood debris:
Large pieces of organic matter, such as tree trunks and branches. No formal size distinction exists, but pieces are generally greater than 3 meters in length and 10 cm in diameter.